3

Processing plants and equipment

The process of yoghurt production has evolved through the ages from a simple preparation carried out in the home on a very small scale to medium and large-scale production centres handling many thousands of litres per day. The utensils and equipment required vary in relation to the type of yoghurt produced, scale of production and the level of technology adopted. Hence, it would seem logical to review the available equipment and plant against a scale of yoghurt produced per day:

- Home or small-scale production
- Medium-scale or manufacture by a small producer/retailer
- Large-scale production

3.1 Home or small-scale production

Traditionally, yoghurt is prepared at home and ordinary kitchen utensils are used. The milk is heated in a cooking pot and the production of the coagulum takes place in the same container; Fig. 2.1 described briefly the overall process. However, one factor which is critical during the incubation period is the maintenance of a uniform temperature. This is achieved by wrapping the pot in a woollen blanket and placing it in a warm place, for example, near a cooker. Although the traditional process could still be recommended to individuals producing their own yoghurt, a simplified recipe is illustrated in Fig. 3.1.

The linen airing cupboard (i.e. area beside the hot water cylinder in a modern house) is sometimes used during the fermentation period, although yoghurt "makers" (Fig. 3.2) have become available for enthusiasts to produce yoghurt under controlled conditions (see also Taylor, 1981; Light, 1993; Hyman *et al.*, 1996). Alternatively, warm milk inoculated with the starter culture (or natural yoghurt) is placed in a wide mouth Thermos flask and left undisturbed, allowing the milk to ferment and coagulate. Cooling is carried out directly after coagulation has taken place and fruit and/or sugar are normally added to the cold yoghurt.

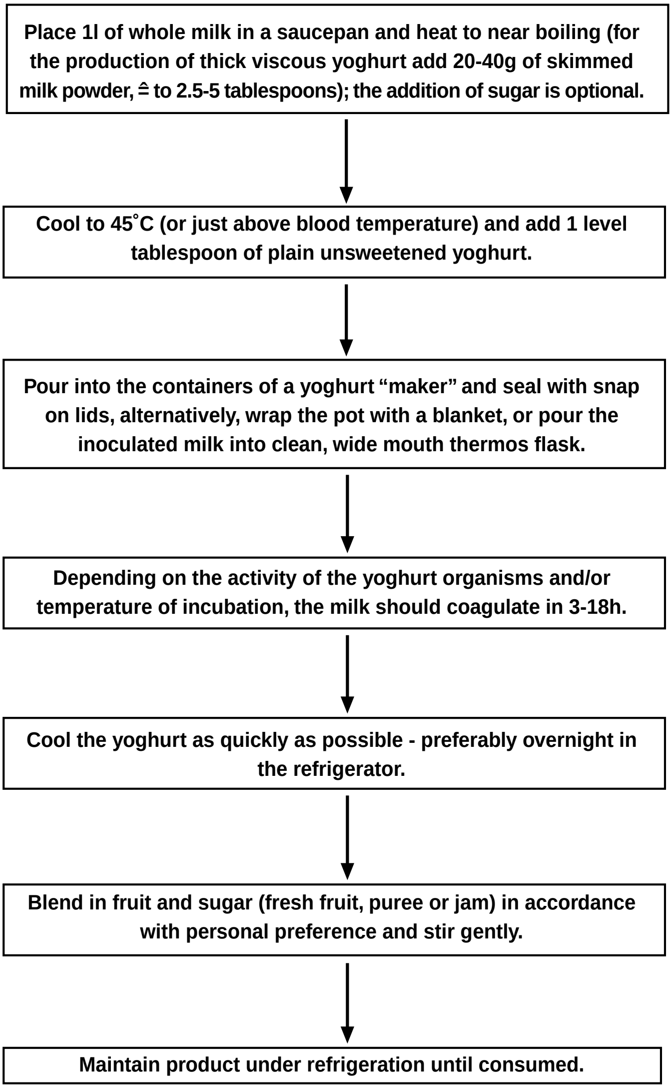

Fig. 3.1 Production of yoghurt at home

Note the following: (a) one pot of the natural yoghurt produced could be used as a starter culture to inoculate the following batch, (b) excessive subculturing can lead to a prolonged incubation period, and hence it is recommended that a fresh yoghurt should be introduced weekly, and (c) short incubation periods are obtained using fresh, active starter cultures, an approach which is highly recommended.

3.1.1 Miscellaneous systems

The processing steps involved, including the equipment required, in the manufacture of set or stirred yoghurt by this simple procedure are summarised here:

- Milk base is prepared in cans/churns.
- The cans are immersed in a water bath which is required for the heat treatment of the milk; the heat source could be steam or electrical. At the cooling stage, the hot water is replaced by cold water from the mains.

Fig. 3.2 Yoghurt maker where glass jars with screw-on plastic caps are used

- At 45°C milk is inoculated with starter culture and incubated in bulk (stirred yoghurt), or for set yoghurt the milk is dispensed into cups prior to incubation; special cabinets can be used for the fermentation, or alternatively the temperature in the water bath can be maintained at 42–45°C to ferment the milk in bulk.
- At the desired acidity the cans/churns are removed from the incubator unit(s) and stored overnight in the cold store.
- Fruit is added separately to each can/churn and mixed gently using a milk/cream plunger.
- Filling and packaging is carried out using hand-operated units (see below).

3.1.2 Packaging system

For this scale of yoghurt production, it is inappropriate to install a proper packaging machine due to the high capital investment required. Subsequently, the yoghurt is packaged using hand-operated unit(s), but extreme care should be exercised in order to minimise contamination of the product. Figure 3.3A shows how yoghurt can be produced in a 10 litre stainless steel churn, followed by the addition of fruit on top of the cold yoghurt and mixing. The fruit flavoured yoghurt is dispensed into plastic cups manually using a stainless steel jug, and finally the aluminium foil lids are crimped in place (Fig. 3.3B–E). Incidentally, an improved method of closure of the yoghurt cups uses a hand-operated heat sealer.

An alternative method of packaging very small volumes of yoghurt per day involves use of a small-scale cup filler. A typical example is the CD 500/1000 machine (see Fig. 3.4). This unit is capable of filling yoghurt cold or hot, and the filling head is fitted with an antifoam nozzle. The capacity of filling ranges between 85 and 600 ml or g, and the piston used for filling the yoghurt has an easy measure adjustment with a fine setting.

The sequence of operations could be described as follows: place the yoghurt cup on the tray and press the foot pedal; the machine will dose out the set measure of

Fig. 3.3 Hand filling of yoghurt cups

product. The filling head automatically resets when the cup filling sequence is complete and the filled cups are then heat sealed using a separate unit (Fig. 3.4B). The speed of filling depends on the cup capacity and the speed of the operator but, in general, the cup filling speed ranges between 10 and 20 containers min^{-1}.

Alternatively, paperboard cartons could be used for the packaging of yoghurt using a hand-operated cartoning and filling machine (Fig. 3.5). This method of filling yoghurt could be referred to as a hand form/fill/seal operation. The hand-operated bottom carton sealer (Fig. 3.5A) preforms, crimps, heats, folds and bottom seals all sizes of carton, and pre-breaks the tops in preparation for the "top sealer"; incidentally, a similar unit was illustrated in the previous edition of this book and the design has been changed to include an air-operated base sealing plate.

The hand filler/sealer is basically designed for liquid milk but, by slightly modifying the filling head, it becomes feasible to fill a viscous product such as yoghurt (see Fig. 3.5B). The preformed cartons are placed under the filler and a microswitch operates the time fill. Then, the carton is pushed under the sealer and the handle is pulled to seal it. The speed of both the hand carton/sealer and the filling/sealing machine is about 10 units min^{-1}.

(A) (B)

Fig. 3.4 Small filling machine (A) and a thermostatically controlled heat sealer for aluminium foil lids (B)

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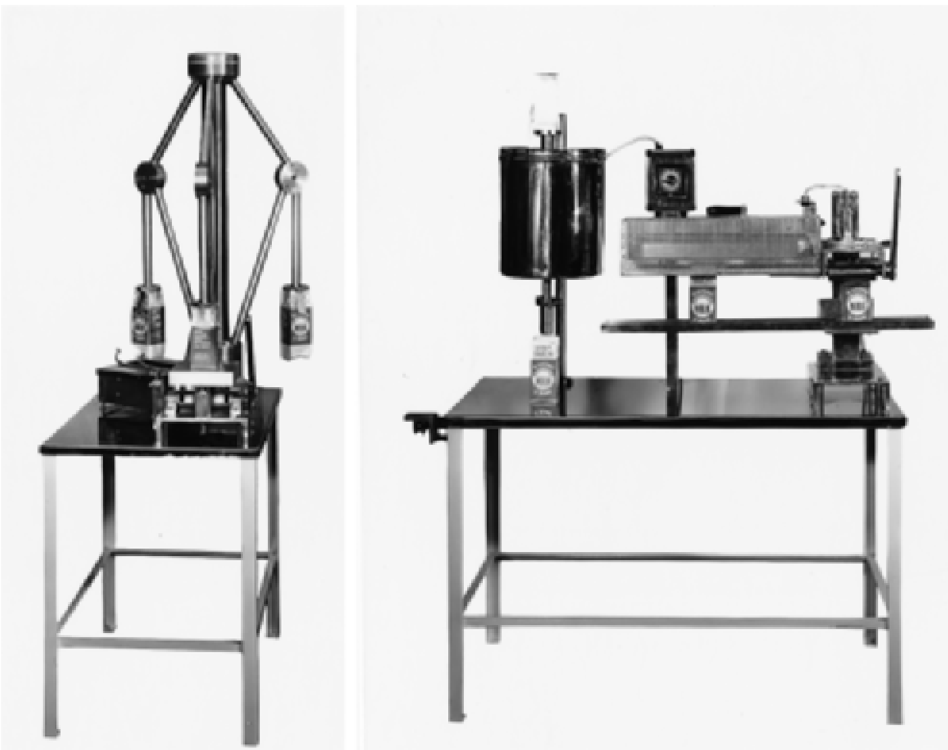


(A) (B)

Fig. 3.5 Hand-operated packaging equipment for filling yoghurt into cartons

A, Carton maker/sealer; B, hand filler sealer.

Reproduced by courtesy of C.K.X. Engineering, Sudbury, U.K.

3.2 Medium-scale production

The volume of yoghurt production in this category is rather low, perhaps in the region of a few hundred litres per day, and such small producer/retailers aim to market their yoghurt within a limited area. The different types of equipment which could be used at this level are described below.

3.2.1 Hand-operated vat

In some parts of the world, equipment manufacturers may produce specially designed small processing vessels (i.e. hand-operated, multipurpose tanks) where the agitation of the milk base during heating and cooling is done manually. The different steps involved during the production of yoghurt can be summarised as follows:

- Sanitise the equipment directly before using chemical sterilising agents, drain and rinse with clean water.
- Pour the milk into the vat, add the required amount of dried ingredients (milk powder) and mix with the aid of a stainless steel wire whisk.
- Start the heating cycle using an electric element to heat the insulated water jacket and hand agitate the milk.
- After reaching the desired temperature, the heating element is switched off and the milk is held for 10–30 min (depending on temperature), prior to cooling.
- During cooling, the water in the jacket is replaced by circulating mains water. At 40–45°C the milk is inoculated with starter culture and left undisturbed during the fermentation period.
- After a few hours, or at the desired acidity, mains water is circulated through the jacket to cool the coagulum, a process that may be assisted by gentle agitation.
- At around 15–20°C, a known volume of yoghurt is drained out, mixed with fruit/flavouring additives and hand-filled into plastic cups.

3.2.2 Multipurpose vat

This type of vat is really a batch pasteuriser which is slightly modified to meet the requirements of yoghurt manufacture and it is widely used for the production of viscous yoghurt (Fig. 3.6). These vats are usually made of stainless steel and insulated with a water jacket. The capacity may be in the region of 50–2250 l. When this type of vat is used, the processing stages of stirred yoghurt production usually follow two alternative patterns. In the first approach the vat is utilised for all the different steps necessary for the preparation and production of yoghurt (Fig. 3.7, process A). However, in the second approach the vat is merely used for the preparation of milk, that is, mixing the dried ingredients with milk, heat treatment and cooling to incubation temperature (Fig. 3.7, process B).

Processes A and B described in Fig. 3.7 illustrate clearly the steps necessary to produce stirred yoghurt, but for the manufacture of set yoghurt, process C (Fig. 3.7) should be followed. Processes B and C are similar except that in process B the milk is fermented in bulk, while in process C the milk is incubated in the retail container. The major differences between set and stirred yoghurt are illustrated elsewhere (see Chapters 2 and 5).

The multipurpose vat (Fig. 3.6) can be heated using different sources of energy (e.g. electrical, steam or gas) and this versatility makes this type of processing equipment very popular with the small producer. During the cooling stages, mains water

Fig. 3.6 Typical batch pasteuriser which can be used as a multipurpose vat for the production of yoghurt

Gusti-steam, electric or gas heated “Pastomix” – “Pastolux” vat for heat treatment of the milk base or cold storage of yoghurt (see text).

Reproduced by courtesy of T. Gusti, Wellingborough, U.K.

can be used or a closed-circuit cooling system circulating chilled water may be employed. However, if in-tank cooling is used for cooling the yoghurt, a slow speed agitator (i.e. <45 rpm) is operated to mix the coagulum gently and assist cooling but, at the same time, inflict minimum reduction in viscosity on the product. The diameter of the outlet valve must be ≥ 5 cm in order to facilitate ease of drainage of the yoghurt. On such a small scale of production, the stages of fruit mixing and filling can be carried out manually, but great care must be taken to minimise post-production contamination. Figure 3.7, process B, illustrates this approach. The fruit is added to each can/churn and gently mixed with the yoghurt by means of a milk/cream plunger.

3.2.3 Mini dairy

The “mini dairy” is a small compact processing plant which was developed in the late 1970s by Alfa-Laval A/B, Lund in Sweden – a project sponsored by the Swedish

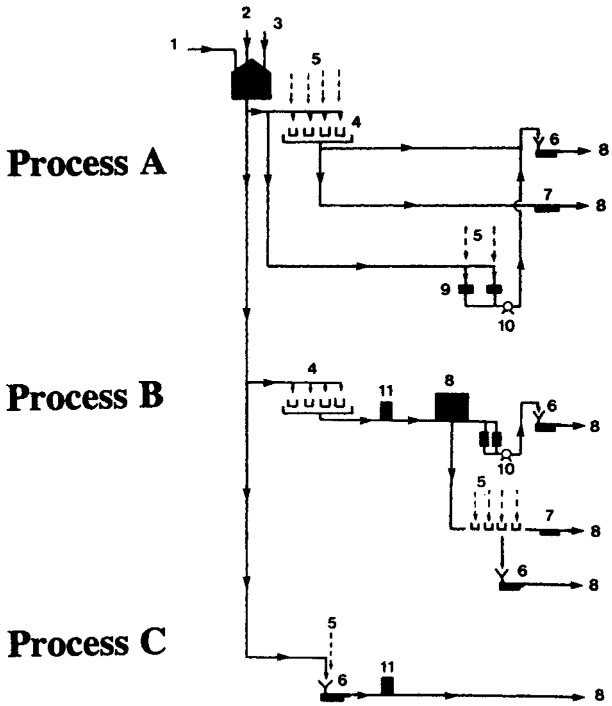


Fig 3.7 Small-scale production of yoghurt using a multipurpose tank

1, Inlet for liquid milk; 2, dried ingredients (milk powder(s) and sugar) added manually; 3, starter culture added manually; 4, stainless steel churns (process A – contain cold yoghurt or process B – processed milk base inoculated with starter culture); 5, fruit added manually; 6, small-scale filling machine; 7, hand filling machine; 8, cold store; 9, two small tanks (in parallel) used for the addition of fruit with yoghurt so that filling can be continuous; 10, positive pump; 11, incubation cabinet for set yoghurt (process C).

government to establish small-scale milk processing units in the developing countries. At present, Tetra Pak and Alfa-Laval Agri are responsible for marketing of these units in different parts of the world. The mini dairy unit is basically designed for processing market milks, cheese and fermented milks. For yoghurt, for example set, stirred and/or drinking type, the unit is capable of producing 10001 per batch over an extended 8 hour shift. All such units are pre-assembled and tested to give a short and efficient installation and start up time. The energy required for heating and cooling is provided by mains electricity or a diesel powered electric generator and hot water is generated by an oil- or wood-fired furnace. Figure 3.8 illustrates a unit for processing milk for the manufacture of the products mentioned above (Gandhi, 1986; Caviezel, 1987; Briem, 1992; Olivetti, 1993; see also Capogna *et al.*, 1997).

3.2.4 Small-scale packaging machines

Although hand filling has been adopted by many small dairies, the use of a proper filling machine does offer some advantages. A wide range of fillers is available on the market, and these filling machines are equipped with a diversity of sealing mech-

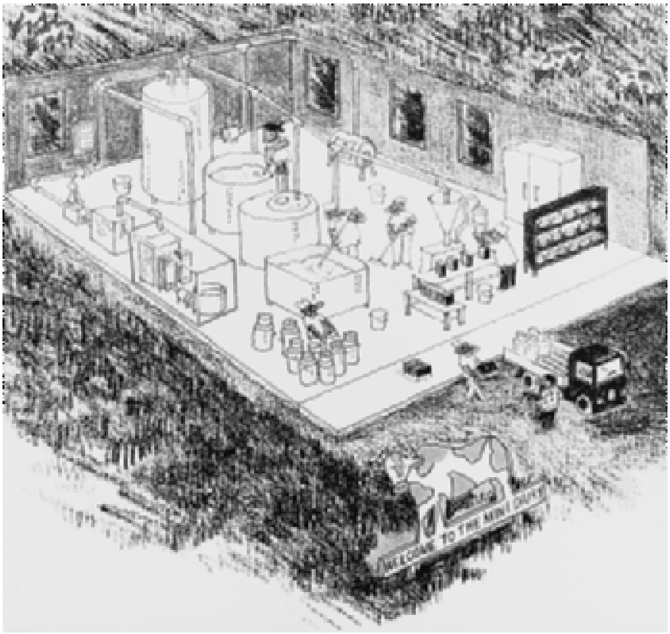


Fig. 3.8 General view of a mini dairy processing plant
Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

anisms, for example the ability to heat seal foil lids, crimp foil lids or snap-on plastic lids. The ultimate selection of a particular type is largely a matter of personal preference (see Platt, 1990). Most manufacturers of packaging machines also produce small-scale equipment to meet the demand from small dairies. Some examples follow.

Regal RP/SA2 – This machine is semi-automatic and consists of:

- stainless steel hoppers that hold the yoghurt and the fruit base
- stainless steel rotary table
- a foil dispense assembly with a spot sealer
- heat sealing assembly.

An illustration of this machine is shown in Fig. 3.9. The sequence of operation is as follows: (a) the preformed containers are loaded into the machine by hand and a photo-electric cell (PEC) detects their presence, (b) the operator indexes the rotary table clockwise to the filling assemblies, (c) when the container is filled (i.e. with fruit flavoured yoghurt or, in a two-step sequence, with fruit and the yoghurt base, separately), the operator indexes the rotary table clockwise to the foil dispense assembly where a foil is placed automatically and spot sealed in position and (d) the operator then indexes the table to the heater assembly where the aluminium foil lid is heat sealed automatically.

As the operator indexes the rotary table once more, this allows removal of the filled yoghurt containers. However, every time the table is indexed, another container should be loaded to repeat the cycle. The volume of the fruit dispensing unit ranges from 10 to 80 ml, and for yoghurt 60 to 300 ml. Incidentally, the machine is

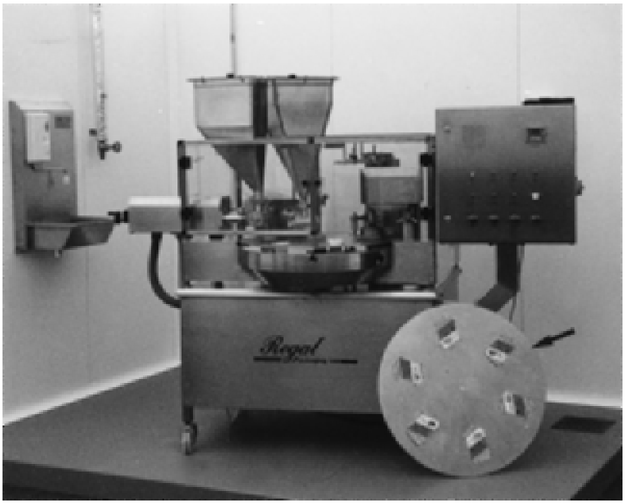


Fig. 3.9 General view of the Regal semi-automatic

Note: Arrow indicates stainless steel table specially designed for filling twin chamber container.

fitted with a fully interlocked stainless steel mesh safety guard. The same manufacturer produces fully automatic filling machines up to 12000 cups hour^{-1}.

Waldner Dosomat 1 Eco, 1, 2 & 10 – These are rotary cup filling and closing machines that cover capacities ranging from 1000 to 20000 cups hour^{-1}. These machines are fully automatic with the dosing unit mechanically driven; this unit operates on the piston principle that ensures filling with absolute care and accuracy. For viscous products like yoghurt, product aspiration is realised by direct feed via equalising pistons and the dosing range is regulated by handwheel. A range of containers (e.g. cartons, plastic pots or glass bottles) can be used on this machine for packaging yoghurt. Figure 3.10 illustrates one example operated within a laminar flow cabinet hood. All models of the rotary Dosomat machines are fitted with a coding system of one of the following types:

- coding with quick drying ink or hot stamping with ink ribbon on the lid or cup bottom
- heat or cold embossing into cup bottom
- labelling
- ink-jet

The closure of the container (i.e. heat sealing with a snap-on lid) can be achieved by heat, ultrasonic or high frequency sealing. All models are suitable for clean-in-place (CIP). Incidentally, the number of filling lanes on the rotary table ranges from one up to eight depending on the model and throughput.

GEI Turbo Rotafil – This is a multifunctional compact system of filling. The machine is available with different sizes of interchangeable indexing table for packaging into a wide range of container sizes. It can be supplied with many optional features such as:

Fig. 3.10 Waldner Dosomat rotary-type yoghurt filling machine
Reproduced by courtesy of Ultrapak, Aldershot, U.K.

- automatic container dispenser and discharge systems
- multistation or filling head facilities
- automatic closure, heat sealing and securing of antitampering devices
- date and price coding system.

The filling speed is around 8400 pots hour^{-1} on a four-head production system. However, the specially designed filling head (see Fig. 3.11) ensures that there is a regulated speed of filling, capacity to deliver fruit pieces intact into fruit flavoured yoghurt, and (c) virtually drip-free cut-off between the fills.

Cockx R 4000 – The machine is a 16 pocket, eight station unit with options of prefill and overlid (Fig. 3.12). In general, it is fitted with cup magazines, mechanical main piston fill, lid appliers, heat sealers, date coders and cup ejection onto a conveyor with an extended collection table; the filling speed is about 4000 cups hour^{-1}.

The machine has been designed to allow, if required, two different products to be filled at the same time as the starwheel indexes two pockets at a time. The filling valves are independent and, as an extra, two hoppers can be fitted as an alternative to the single unit. If the pre-fill extra is used, then larger capacity cups can be filled faster with a pre-dose prior to the main fill. The nozzles can be changed for different products and have a positive cut-off. The measure adjustment is inside the main frame of the machine, easily accessible through the interlocked doors. The lid magazines can be switched independently and can be changed for containers of different rim size. The heat seal heads have easily changeable seal plates and the date coders can be quickly adjusted for height and position. The filled and sealed cups are raised out of the pockets and swept onto a deadplate prior to being pushed onto a small conveyor where they are guided onto a collection table for packing.

Fig. 3.11 Filling heads on Turbo Rotafil packaging machine
Reproduced by courtesy of GEI International, Woburn Sands, U.K.

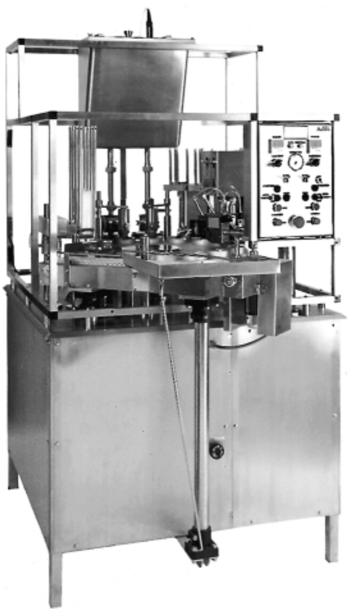


Fig. 3.12 Cockx rotary cup filler and sealer
Reproduced by courtesy of C.K.X. Engineering, Sudbury, U.K.

The fill, lid application and heat seal systems are all controlled by sensors and all doors are fully interlocked for safety. There are no process controllers fitted to the machine and the mechanical variable speed drive is connected to the piston fill drive system by a chain and is also connected to a camshaft. This camshaft has a series of roller operated valves operated by individual cams which are easy to set up or adjust. In this way, it is easy for the customer fully to understand the working of the machine at each station. Lubrication ports are on one panel with the feeds through copper tubes to the bearings.

3.3 Large-scale production

In this category, the equipment employed for the manufacture of yoghurt is specially designed to handle thousands of litres per day and a highly sophisticated technology has evolved which offers a dairy both improved mechanisation and automation. Since the publication of the first edition of this book, few technical developments have occurred with respect to yoghurt technology and the latest technological progress in this field has been reviewed in two International Dairy Federation monographs (IDF, 1988, 1992). Driessen and Loones (1992) presented a comprehensive chart summarising the new developments in technology including products with special micro-organisms and these are:

- Membrane techniques which make it possible to utilise the required properties and avoid the unwanted properties of microbial metabolites.
- Separate cultivation which makes it possible to combine micro-organisms that need differing conditions for their proliferation, for example, mesophilic and thermophilic strains.
- Applying automatic pH control to end the fermentation process and achieve a more consistent product.
- Mounting the cooler on top of the filler, to achieve better viscosity in stirred fermented milks.
- Applying in-line inoculation which makes manufacture of set fermented milks more flexible.
- Overpressure of sterile air which has proved to be effective in protecting starters against contamination with other micro-organisms and bacteriophages.

The topic has been extensively reviewed elsewhere (Anon., 1981a, b, 1983a; Salji *et al.*, 1985; Evavoll, 1985; Nicolaus, 1987; Bianchi-Salvadori, 1989; Driessen and Loones, 1990, 1992; Nilsson and Hallström, 1990; Robinson and Tamime, 1990, 1993; Puhan *et al.*, 1994a, b; Nilsson, 1994; Strahm and Eberhard, 1994; Bylund, 1995; Karagozlu and Gonc, 1996; Gardini *et al.*, 1996). As a consequence, it was decided that only up-to-date information will be provided here.

The diversity of these technologies can be discussed most easily in relation to:

- type of yoghurt produced (e.g. set or stirred)
- effect of mechanisation on the quality of the yoghurt
- application of automation to the manufacture of yoghurt.

There are several approaches that can be employed for the production of yoghurt and, as each yoghurt manufacturer has his own specific requirements, each plant is supplied, in effect, tailor made. It is evident that plants which produce set and stirred

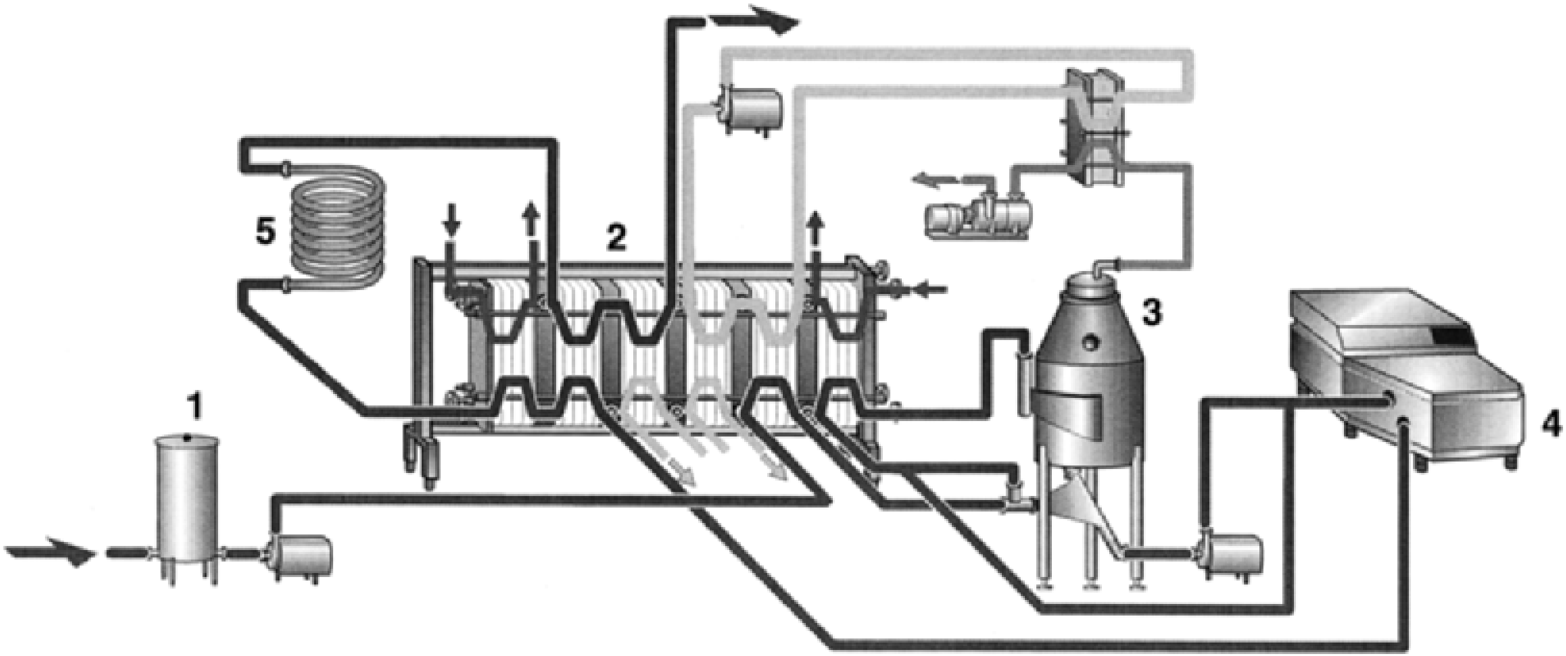


Fig. 3.13 Flow diagram of general pretreatment of milk for the manufacture of set and stirred yoghurts
1, Balance tank; 2, plate heat exchanger (PHE); 3, evaporator; 4, homogeniser; 5, holding tube.
Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

yoghurt (or a combined processing plant) have some stages in common (see Fig. 3.13), for example, milk reception and handling, preparation of the milk base, homogenisation of the yoghurt milk and heat treatment, and hence it is appropriate to review the relevant equipment in relation to the different stages of manufacture; more specialised units are discussed separately.

3.3.1 Milk reception, handling and storage

At present, milk collection from farms in the United Kingdom, developing and industrialised countries is carried out in bulk using a road tanker, although in some instances, rail tankers or churns could be used. The facilities provided at a typical dairy for reception of this bulk milk have been described by Tamime and Kirkegaard (1991) and Bylund (1995) (see Fig. 3.14). The milk intake can be either metered using a metering pump, or weighed (e.g. at a weighbridge for road tankers or in a duplex weighbowl for churns). When milk is accepted, and after a sample for chemical and microbiological analysis has been taken, the general practice for handling the milk may include: (a) filtering the milk to remove contaminants (e.g. straw, hairs, soil) with the most universal system used being a stainless steel filter; however, an optional treatment to clean the milk is clarification using a separator; and (b) cooling the milk to <5°C using a plate cooler prior to storing in a silo.

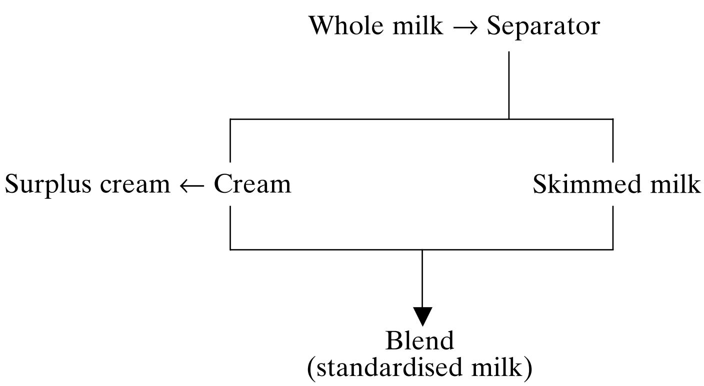
The reception of milk in churns is somewhat different from that from a road tanker. Normally the churns are unloaded in the reception area and the lids removed. The freshness of the product is quickly determined by sniffing the churns and if any unusual smells are noted, the milk is rejected; a composite sample of milk from each farm is further analysed chemically and for bacteriological quality.

As already discussed elsewhere (see Chapter 2), the milk is subjected to a number of preliminary treatments before it becomes yoghurt. These processes are standardisation of the fat content, fortification of the solids-not-fat (SNF) and homogenisation and heat treatment of the milk base. These treatments will be discussed separately.

3.3.2 Standardisation of fat content in milk

The fat content of milk can vary according to source and season, but in yoghurt the level is prescribed by consumer taste or the Statutory Instruments of the countries concerned, so that standardisation becomes essential.

The theoretical approach to milk standardisation can best be visualised as follows:



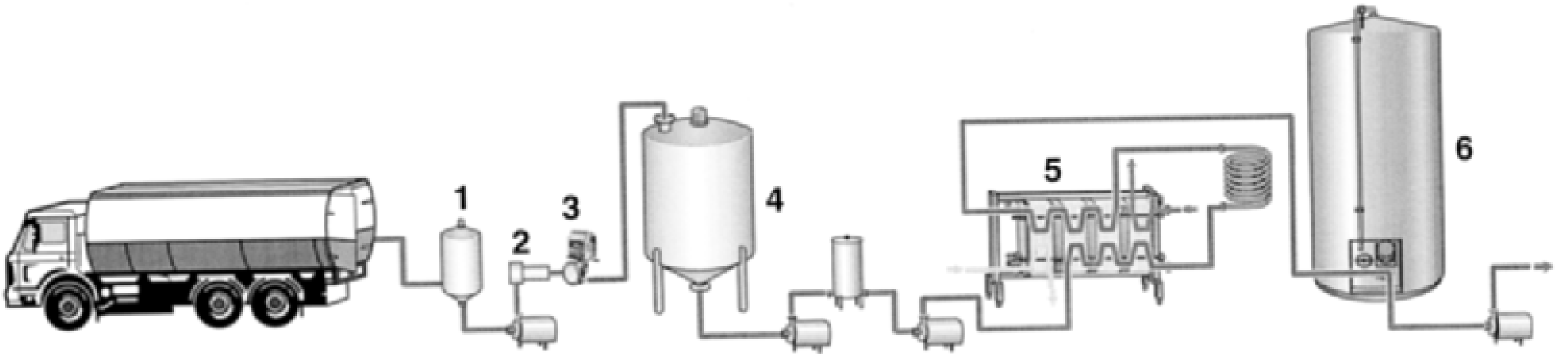


Fig. 3.14 Milk reception, handling and storage at a large factory

1, Air eliminator; 2, filter; 3, milk meter; 4, intermediate storage tank; 5, thermisation and cooling or cooling only; 6, silo tank.

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and the accuracy of the process is dependent on such factors as:

- type of equipment used and the efficiency of fat separation obtained
- control system used.

The skimming efficiency of the available plant has greatly improved over the years, so that residual fat in skimmed milk usually falls between 0.05 and 0.07 g 100 g^{-1}; the skimming efficiency of the separators is thus referred to as 0.05–0.07, respectively. The control system employed in milk standardisation lines can be either manual or automatic, and while the former may be recommended for small/medium size producers, the automatic system is essential for dairies handling large volumes of milk per day.

A number of different systems can be used for milk standardisation (Hellström, 1986; Anon., 1992, 1996a; Bird, 1993). The efficacy of any one particular system depends on its ability to ensure that:

- The pressure of the skimmed milk at the outlet pipe is lower than the pressure in the tank where the skimmed milk and cream are remixed.
- The fat content in the cream remains constant; the proportion of cream remixing with skimmed milk can be stabilised, i.e. there are proportional mixing controls.
- The final fat content of the process milk is within preset limits.

Compomaster KCC – This is an automatic system for standardisation of the fat content in the milk and surplus cream (Fig. 3.15). This unit is directly connected to a separator; however, when liquids are mixed continuously in volumetric proportions, the Compomaster can be used without a separator. In this system of standardisation, combined mass flow meters, density meters and temperature transmitters are used to measure the cream and skimmed milk, respectively (Hansen, 1996). Thus, by knowing the density and temperature of both skimmed milk and cream, it is then possible to calculate the fat content of the cream. The unit automatically adjusts to the set points for the fat content in both standardised skimmed milk (1–5 g 100 g^{-1}) and cream (18–50 g 100 g^{-1}).

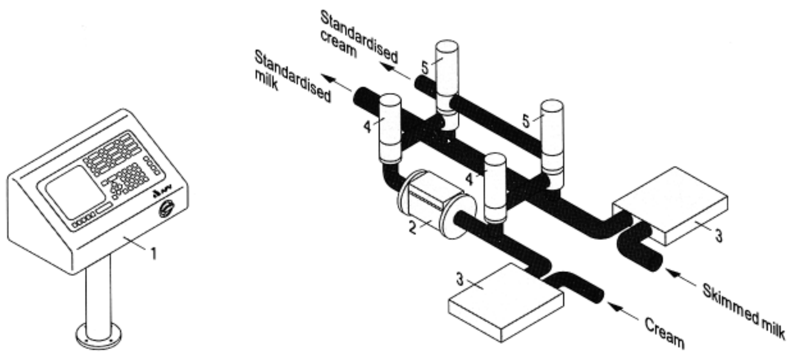

Fig. 3.15 An illustration of fully automatic in-line standardising system

1, Control panel; 2, flow meter; 3, density transmitters; 4, regulating valves; 5, on/off valves. Reproduced by courtesy of APV Nordic, Denmark.

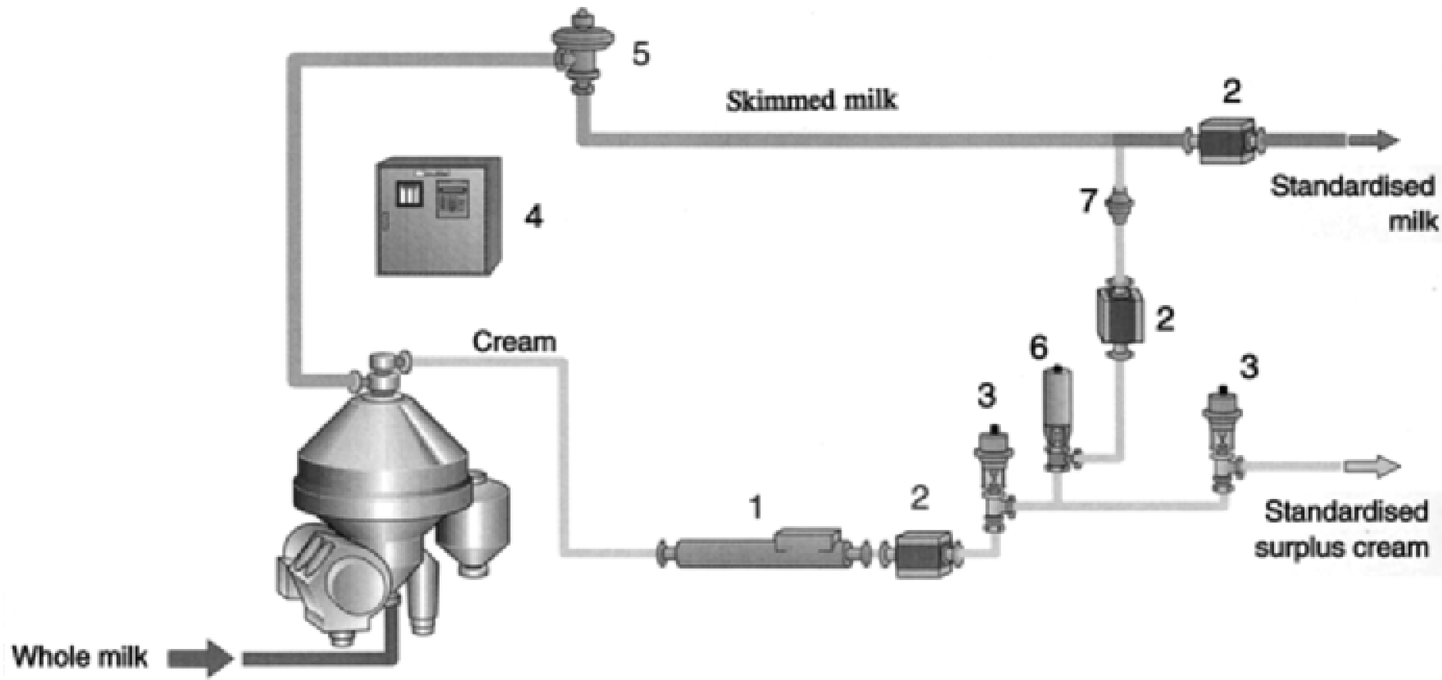

Fig. 3.16 Illustration of an automatic direct standardisation (ADS) system for milk and cream
1. Density transmitter; 2, flow transmitter; 3, control valve; 4, control panel; 5, constant pressure valve; 6, shut-off valve; 7, check valve.
Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

The Compomaster has capacities ranging between 7000 and 45000 l hour^{-1}. It is delivered as a compact unit ready for installation and connections need to be made to the product inlet, air-line and the mains electricity supply. According to Hansen (1996), the Compomaster type KCC standardising system needs to be calibrated only once every second year reflecting the high precision of the unit. This system also contains in-line mixers for special applications (i.e. mixing cream and skimmed milk) without the use of a separator; furthermore, this system is suitable for CIP application.

Automatic Direct Standardisation (ADS) Systems – These methods of standardisation of the milk and cream are very accurate and depend on a careful choice of components and the design and engineering of the system. A typical system is shown in Fig. 3.16, where the components within the system are clearly identified. In brief, according to Bird (1993) and Bylund (1995), the ADS system can be described as follows.

The set points for standardised cream (or surplus cream) and milk fat content are fed into the process control unit. The pressure control system at the skimmed milk outlet (Fig. 3.16 (5), constant pressure valve) maintains a constant pressure, regardless of fluctuations in the pressure drop over downstream equipment. The cream regulating system maintains a constant fat content in the cream discharged from the separator by adjusting the flow of cream discharged. The ratio controller mixes cream of constant fat content with skimmed milk in the correct proportion to give standardised milk with a specified fat content. The accuracy of the system, based on standard deviation of repeatability, should be <0.03% for milk and about 0.25% for cream (see also Hellström, 1986; Anon., 1992).

The application of these systems to the manufacture of yoghurt could be considered under the following conditions: (a) if the solids content of the milk is fortified using an evaporator (Fig. 3.13 and 3.17), then it is necessary to standardise the fat content in the milk before the concentration process commences, (b) skimmed milk could be concentrated by evaporation and then before further treatments (i.e. homogenisation and heat treatment) the concentrated skim could be standardised with cream, (c) concentrated skimmed milk may be standardised with cream, and (d) membrane filtration (UF (ultrafiltration) or reverse osmosis (RO)) is sometimes used to concentrate the milk base. Normally, the fat is separated from whole milk and the skimmed milk is concentrated to the desired level of solids; the concentrated skim fraction is then standardised with the cream.

In general, therefore, the milk base is standardised for fat content before evaporation commences but, if the skimmed milk is concentrated in a UF plant, the addition of cream takes place later. The reason for adding the fat to the concentrated skimmed milk in the latter method is that the high pressure used during the concentration process could damage some of the physical properties of the fat, which in turn may affect the quality of yoghurt (e.g. an oiling-off or a churning effect).

3.3.3 Fortification of milk solids

The level of milk solids in the milk base can be raised by one or more of the following methods.

3.3.3.1 Traditional process

Boiling the milk can be carried out in a tank similar to a batch pasteuriser. The aim of this approach is the evaporation of one-third of the milk volume under

Fig. 3.17 View of an internal evaporation and de-aeration plant used on a yoghurt processing line

Reproduced by courtesy of APV Nordic, Denmark.

atmospheric pressure. However, this method of concentration of the milk solids is not used under industrial conditions, mainly due to the high cost involved, but also because the generation of too much steam in the processing area can be unacceptable to personnel.

3.3.3.2 Addition of milk powder

Different types of milk powder can be used to fortify the yoghurt milk (see Chapter 2), although skimmed milk powder is used most widely. The dried ingredients are incorporated into the aqueous phase which could be whole milk, skimmed milk or water, and the available equipment is designed to provide: (a) complete dispersion of the dried ingredients into the aqueous phase, (b) complete hydration of the dried particles with no residual lumps, (c) minimal incorporation of air in order to reduce the problems of foaming, and (d) the capability to clean and sanitise the unit easily.

The powder-handling equipment found in a dairy is dependent on the daily throughput and the method of bulk delivery. Basically, milk powder is packed into either small capacity units (25–50 kg multilayer paper sacks with polythene liners), or medium capacity units (up to a tonne in metal or plastic containers), or road tankers for bulk storage in metal silos. The machinery available for emptying the powder also varies, so that while the sacks (small quantities) may be emptied directly into reconstitution units, larger volumes are emptied into a sifter for deliv-

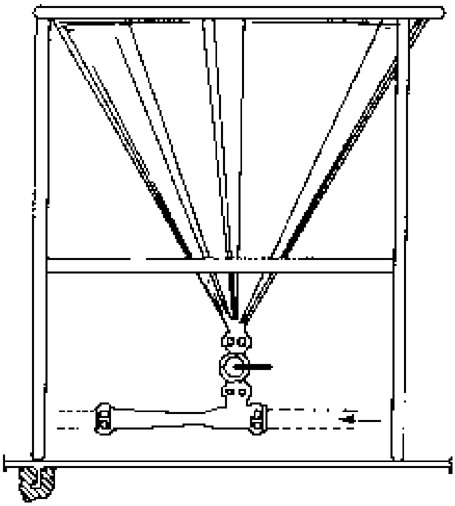

Fig. 3.18 Illustration of a mixing funnel/hopper used for the reconstitution of milk powders

The sack of milk powder is placed on the table and then emptied into the funnel. The force of the circulating liquid causes the powder to be aspirated downward and mixed with the water. Circulation is continued until the powder is dissolved. Notice that the funnel has a valve connection, which has a slight constriction/restriction in the pipe to provide a venturi effect.

ery into the mixing unit. The powder stored in metal/plastic bins or silos is transferred using either a screw-feed (of variable speed) or a blower; dust filters must be used to recover any fine particles, especially in plants handling large capacities. Some examples of milk powder mixing units are given below.

Mixing funnel/hopper – Reconstitution of the powder is carried out in batches and a "closed circuit" consisting of a tank, pipe connection, centrifugal pump and the funnel/hopper assembly is required. The tank is normally filled with the aqueous phase at around 40–50°C and the circulation started. The positioning of the hopper in relation to the centrifugal pump is important and two options are available (see Fig. 3.18).

First, if the hopper is assembled on the suction side of the centrifugal pump, it offers the advantage of rapid dispersal and adequate dissolution of the powder due to the action of the pump; the disadvantage is that frequent blockages may occur in the hopper.

Second, by placing the hopper on the outlet side of the centrifugal pump directly after a specially designed venturi unit, the problem of blockage is overcome, since the venturi unit creates a vacuum within the pipe causing the powder to be sucked into the recirculating solution; full dispersal of powder may be a little slower (Newstead *et al.*, 1979; Sanderson, 1982).

The former circuit is illustrated in Fig. 3.19. It is noticeable that, in the latter approach, any suction of air is returned to the tank rather than the suction side of the pump, because if air is introduced into the system, the action of the pump's impeller can increase the amount of air incorporated into the product. Furthermore, a reduction in aeration and/or frothing can be achieved by installing a special valve

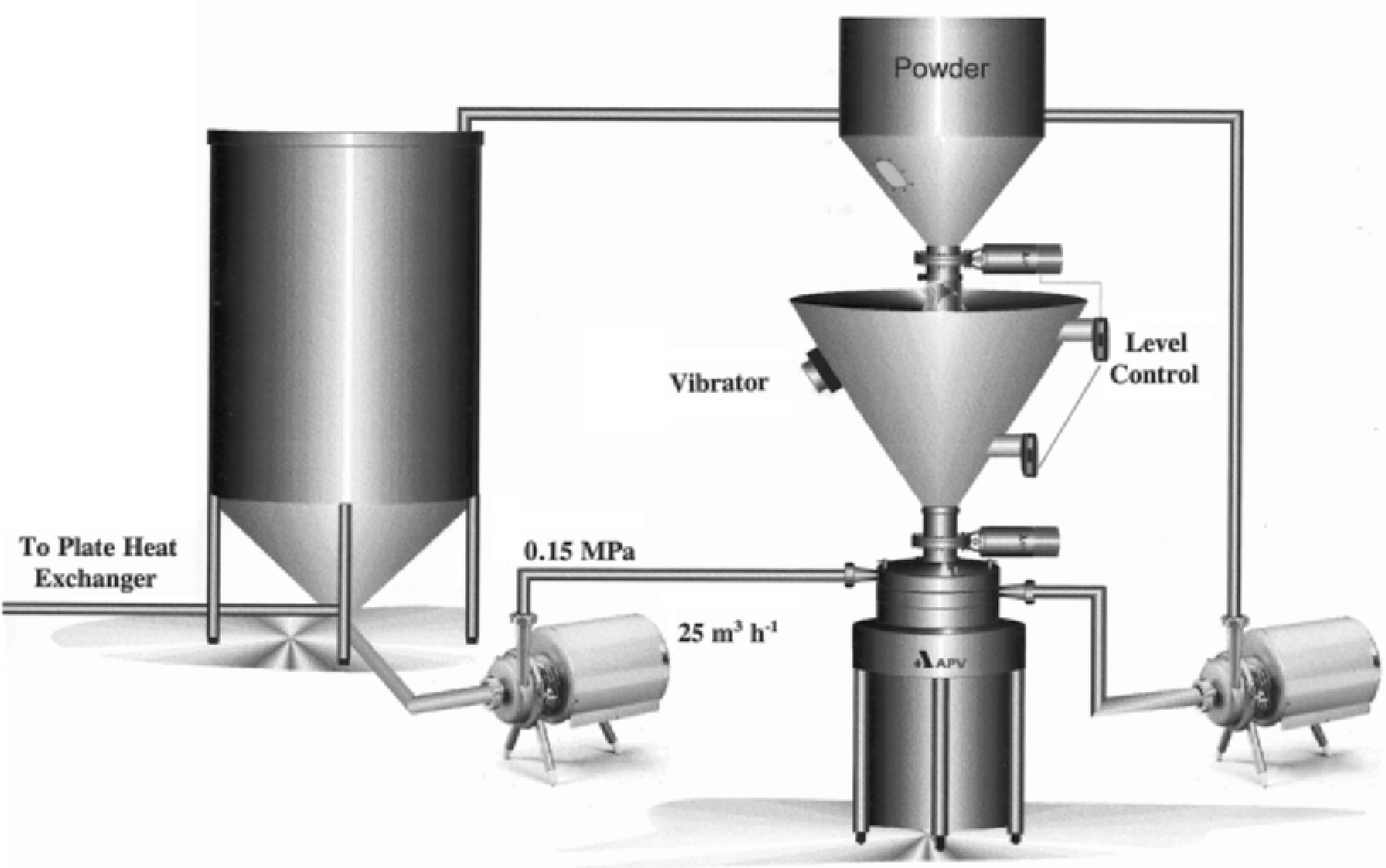

Fig. 3.19 Schematic illustration of TPM-1 powder mixer
Reproduced by courtesy of APV U.K. Co. Ltd., Crawley, U.K.

Fig. 3.20 Tri-Clovers dual-stage Tri-Blender®
Reproduced by courtesy of Tri-Clover Inc., Kenosha, U.S.A.

on the mixing hopper and ensuring that the return line in the mixing tank is below the level of the liquid. If additional mixing of the added powder is required, one of the following units could be employed: (a) in-line static mixer, (b) high speed agitator in the mixing tank, and (c) high velocity liquid jet.

An alternative method to the funnel/hopper installation is the in-line mixer, and some examples of such units are as follows.

Tri-Blender® – This mixing unit is supplied by the Tri-Clover Inc. of Wisconsin, U.S.A. The principle of this mixing unit is that the venturi jet mixer is replaced with a dual stage blending process (see Fig. 3.20). The system is designed for continuous in-line or batch blending of dry ingredients at a rate of up to 45 kg min^{-1}. The product passes through the initial liquid/dry ingredient blending chamber to a second blending chamber which effectively serves as a discharge pump. This double blend feature improves end-product consistency and provides a smoother and more uniform blend. With the discharge pump function handled within the blender itself, it is possible to achieve significantly higher vacuum rates over a wider range of process conditions. The increased vacuum rates contribute to fast and consistent flow rates throughout an entire production run, and with such a blending system, the additional strainers and a discharge pump are not required. Incidentally, this unit is rather compact and occupies only 50 × 75 cm of floor space (see Fig. 3.20).

Silverson mixers – These types of mixer operate at very high speed and exert an homogenising effect during the recombining of dried ingredients. The models, which

Fig. 3.21 The "Flashmix" that can be used for in-line mixing of powders
Reproduced by courtesy of Silverson Machines, Chesham, U.K.

could be used for the reconstitution of milk powder, are known as the "In-Line" and the "Flashmix". The latter unit is shown in Fig. 3.21. These machines are designed for continuous operation at high speeds and each has incorporated a high shear rotor/stator processing workhead; the In-Line mixer has one such head and the Flashmix has two. The upper head is normally a general purpose disintegrating unit, whilst the lower head is a square hole type with high shear screen. The operating characteristics of these workheads are briefly described by the manufacturer:

- The liquid is gravity fed or pumped into the hopper and is rapidly drawn down by the two rotor/stator workheads; a vortex is created by the flow of liquid through the Flashmix, and it is into this vortex that the powder is added.
- The liquid/solid mixture is drawn down the vortex into the mixing chamber and has no way of bypassing the workhead(s) assembly ensuring that all the solids are totally dispersed before leaving the mixing chamber.

Two advantages claimed for the unit are that the workheads can be changed to suit each individual product and that by using the appropriate feeding/metering equipment, the liquid/solid ratio of flow can be precisely controlled. However, a similar

unit known as Flashblend can also be used to wet and disperse powders into liquids rapidly but the mode of operation is different.

The use of an In-Line mixer alone has its limitations, because the delivery of milk powder through a funnel into a recirculating circuit inevitably leads to "arching". However, the use of a Flashmix mixer overcomes this difficulty due to the fact that the liquid and solid ingredients are fed simultaneously into a specially designed hopper before being sucked immediately into the upper rotor/stator. This workhead converts the milk powder/liquid phase into a slurry which is then dispersed as the result of the high speed shearing effect of the bottom or second workhead. It is obvious that each mixer is designed for a particular purpose and a combination of these two types of mixer in the recombining process brings the advantages of both units, that is, the mixing process involves three workheads rather than one or two, so ensuring complete dissolution of the powder with the minimum incorporation of air. Some degree of homogenisation of the mix can be obtained by using different types of stator head or screen on the high speed mixer, so that, for example, a disintegrating effect is achieved using large circular holes or slots, a fine screen produces an emulsification/homogenisation effect and a screen with square holes imparts a high shearing effect.

Vacucam™ – This type of an in-line powder mixer was developed by the Semi-Bulk Systems Inc. in the U.S.A. An overall illustration is shown in Fig. 3.22. The system has the following features: (a) an air-pallet/ejector mixer section conveys, wets and dispenses the powder into the liquid; since the design generates its own vacuum to draw in the dairy powders, the mixer allows total separation of dry handling from wet processing, and also, by introducing the powder within the liquid stream, powder plugging is avoided, (b) the in-line ejector/mixer conveys and mixes the powder on a "skidded system" without using mechanical equipment (e.g. conveyors, rotary valves, receivers and in-tank mixers); this system can be fully automated including CIP, and can operate on batch recycle, single pass or continuous modes and (c) the air cone hopper is designed for easy discharge of powders that can cause delivery problems; details of the construction and principles of operation have been given (Anon., 1996b) and the use of low pressure air or other gases eliminates the bridging effect of the powder in the hopper and facilitates discharge. Incidentally, this system of mixing can be easily used to dissolve sugar into the milk base.

In-tank mixing unit – Efficient mixing of powder in a tank relies entirely on the agitation system provided. The familiar flow pattern which occurs during liquid mixing is illustrated in Fig. 3.23. These patterns are largely influenced by:

- Shape and size of the agitator system (e.g. paddle, turbine, propeller, scraped surface, anchor, etc.).
- Position of the agitator, i.e. top or bottom entering, perpendicular or sloped, and/or centrally mounted or not.
- Speed of rotation of the agitator.
- Shape of the processing vessel, while more specifically the efficiency of mixing is related to speed of rotation of the agitator, velocity difference between the bulk fluid and the agitator; the creation of a vortex, incorporation of air into the bulk fluid and any shearing effects.

All these factors are relevant to the dispersal of powder into the bulk fluid and hence an equipment manufacturer has various options in terms of design.

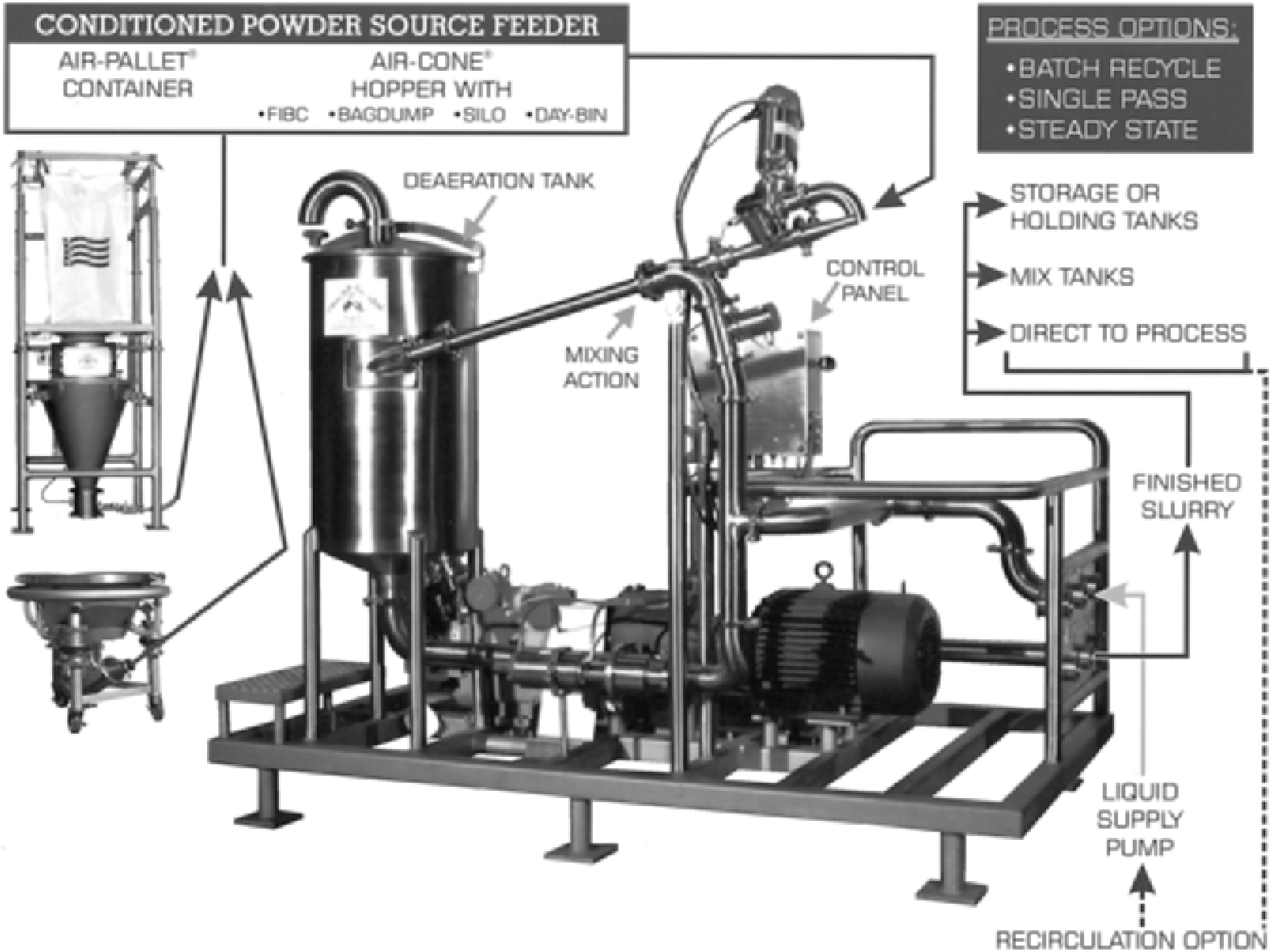

Fig. 3.22 Vacucam™ continuous in-line powder mixing system

Reproduced by courtesy of Semi-Bulk Systems Inc., Missouri, U.S.A.

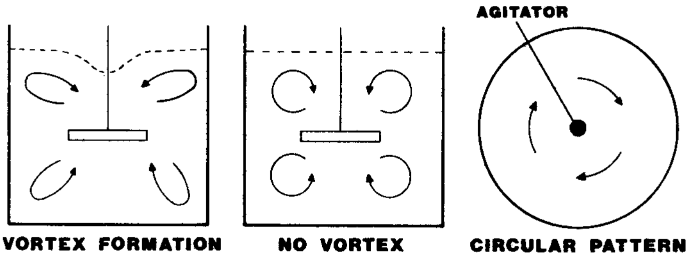

Fig. 3.23 Liquid mixing flow patterns
Note: the paddles are perpendicular, top entering and centrally mounted.
After Tamime and Greig (1979). Reprinted with permission of *Dairy Industries International.*

Multipurpose processing tank – This type of tank (i.e. the batch pasteuriser) can be utilised during all stages of yoghurt making (see Fig. 3.6), since the agitation system consists of a high speed motor which is operated during the preparation and processing of the milk, a slow speed motor for mixing in the starter and later for cooling the coagulum, and the drive shaft of the slow speed motor can be fitted with a one- or two-propeller agitators and is usually top entering and sloped (see also Bylund, 1995).

Simple mixing tank – Different types of high speed mixer (Silverson and Greaves) could be used in simple tanks that resemble a batch pasteuriser, but do not have a properly mounted agitation system. Thus in yoghurt production, two of these tanks will be installed in parallel for preparation of the milk base, so that while one tank is being emptied, the other tank is normally being filled up; a continuous flow of yoghurt milk to the incubation tanks can be achieved in this way. In practice, a tank is filled with water or milk warmed to around 40–50°C and the milk powder is emptied from the sacks. Recombination is achieved using a high shear mixer/homogeniser and the mixers can be mounted permanently in each tank, or alternatively can be removed from one tank to the other with the aid of an hydraulic lift (see Fig. 3.24).

An alternative older type of high speed in-tank mixer is the Ystral mixer described by Dalhuisen (1972). The powder mixing procedure is: (a) powder is emptied into the special chute, (b) the high speed action of the mixing head creates a vacuum at the tip of the powder delivery pipe, thus transferring the powder down the pipe from the chute, and (c) powder/liquid mixing takes place in the absence of air; there is little risk of the powder forming clumps.

Crepaco "Multiverter" – This is a specially designed tank that provides rapid and complete dispersion of the dried ingredients into the liquid slurry. The tank has a 15° or 35° cone bottom which facilitates easy and rapid unloading and it is fitted with a high-speed motor which drives a special centrifugal agitator. This unique agitator incorporates a "squirrel cage" design which results in a dual blending action combining an overall swirl with a deep-draw vortex that quickly and effectively disperses the milk powder into the aqueous phase with a minimum of foam. Although the tank is specifically designed to emulsify two or more immiscible products, the blending action is especially effective in dispersing any fatty constituents in the yoghurt milk. Furthermore, the tank can also be fitted with a CIP system.

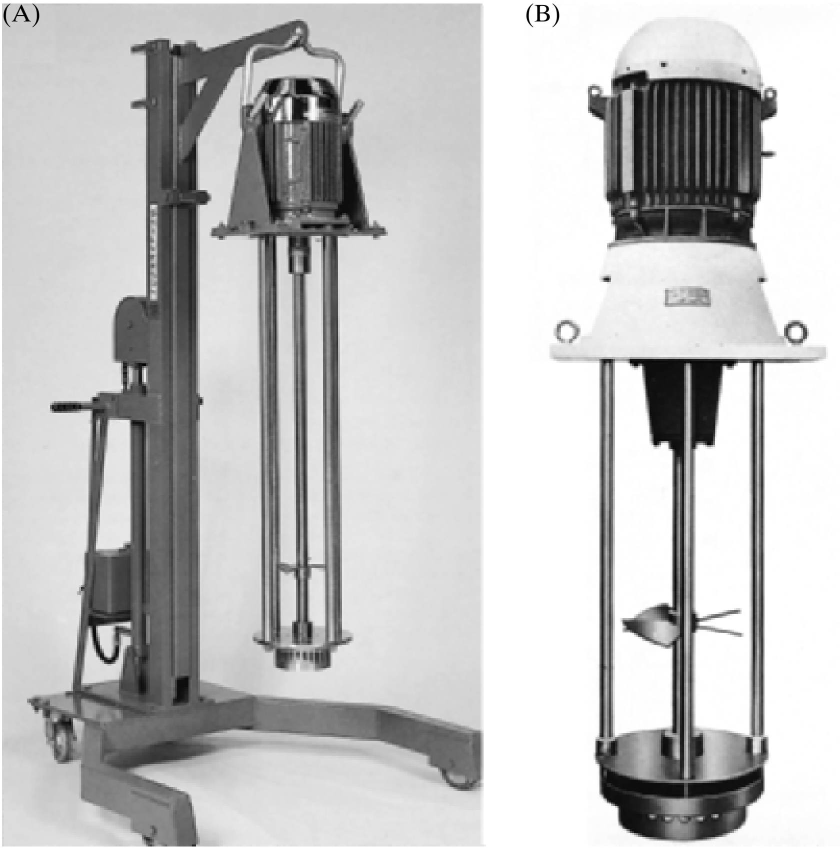

Fig. 3.24 Examples of high speed mobile mixers (A) Silverson and (B) Greaves
Reproduced by courtesy of Silverson Machines, Chesham, U.K. and Joshua Greaves and Sons, Bury, U.K.

Crepaco "Liquiverter" – This high speed mixer/blender is capable of both dispersing the dry ingredients and incorporating fat into the liquid phase. The impeller/agitator is centrally mounted from the bottom of the square tank and the action of the Liquiverter pulls the added milk powder through the liquid vortex at the centre and forces the mixture up the walls in continuous circulation.

Large-scale recombination plant – Two systems could be used during the large-scale production of a milk base (Bylund, 1995; see also Aneja, 1990). In the first system, the fat is dosed into the mixing tank (see Fig. 3.25).

Potable grade water is heated in a PHE to facilitate easy rehydration of the SMP and is metered into one of the storage tanks (see Fig. 3.25 (7)). The circulation pump (5) is started when the tank is half full and water flows through a bypass line from the mixing tank to a high speed powder blending unit (4). The feed rate of skimmed milk powder (SMP) through the blending system is up to 45 kg min^{-1}. A vacuum is created by an interplay between the circulation pump (5) and the booster pump (6) which causes the blender to draw the ingredients into the eye of the centrifugal impeller. The agitator in the mixing tank is started at the same time as the

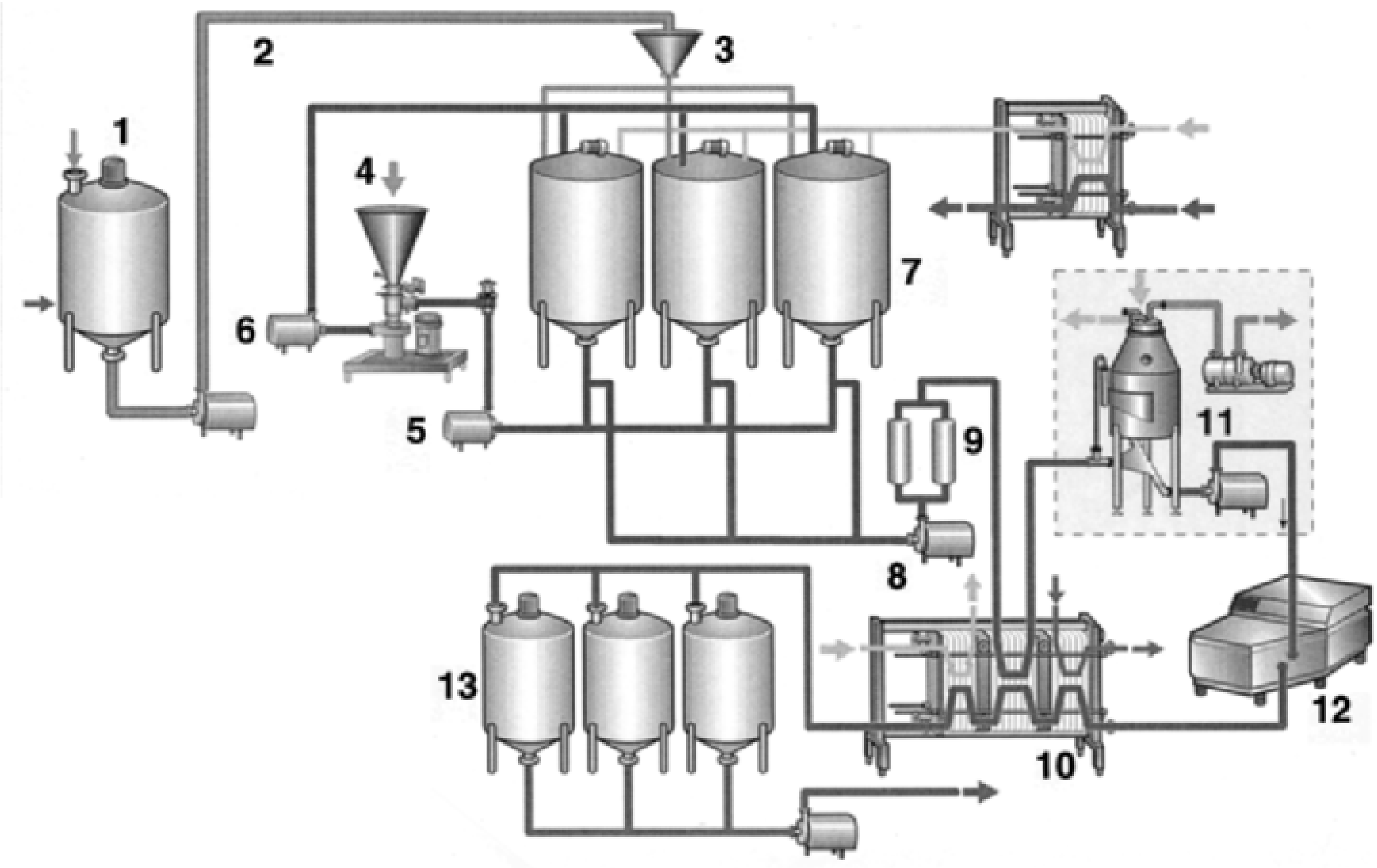

Fig. 3.25 Recombination in a large-scale plant where the fat is added in the mixing tanks

1, Tank containing melted fat (*e.g.* cream or anhydrous milk fat (AMF); 2, insulated pipe for delivery of fat; 3, weighing funnel for fat; 4, funnel with high speed blender (see Fig. 3.20); 5, circulating pump; 6, booster pump; 7, mixing tank; 8, discharge pump; 9, filters; 10, PHE; 11, vacuum de-aerator (optional); 12, homogeniser; 13, storage tanks.

Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

circulation pump. Water continues to flow into the tank while mixing is in progress until the specified quantity has been supplied.

When all the SMP has been added, the agitator and the circulation loop are stopped and the contents of the tank are left until the SMP has dissolved completely. At a water temperature of 35–45°C this will take about 20 min. At the end of this period the agitator is restarted. In the meantime, the blender is reconnected for the next batch to be recombined. AMF is now added from the fat storage tank (1). The quantity is measured in the weighing funnel (3). The agitator, specially designed for optimum fat dispersion, runs for several minutes and finely disperses the fat in the skimmed milk. The piping for the warm fat fraction is normally insulated to prevent the temperature of the fat from falling below the melting point.

When all the ingredients have been mixed and added to one tank, the process is repeated in the next tank. The skimmed milk/fat mixture is drawn from the full mixing tank by pump (8) which forwards the mixture through duplex filters (9). After being preheated in the PHE (10), the product is pumped to the homogeniser (12) where the dispersion of fat globules is completed. During recombination, air might be incorporated into the milk base, and a vacuum de-aerator vessel (11) can be installed in the line before the homogeniser to eliminate this; such a unit can reduce the air content from 1.3–1.8% to 0.1–0.2% which can improve the texture and consistency of the yoghurt (Rage *et al.*, 1987). The product is preheated to 7–8°C above homogenisation temperature before being flashed in the de-aerator, where the vacuum is adjusted so that the outgoing product has the correct homogenisation temperature, typically 65°C. The homogenised milk is pasteurised and chilled in the PHE (10) and is then pumped to the storage tanks (13) or direct to packaging. However, for yoghurt production the milk is heated to higher temperature as described in Fig. 3.13.

Alternatively, in-line fat mixing (Fig. 3.26) can be used in which the recombination of the powder is similar to that described in Fig. 3.25 (Bylund, 1995). In this system, the process could be described as follows. When a mixing tank has been filled and the contents have been given time for complete hydration of the SMP, the reconstituted skimmed milk is pumped through duplex filters (6) to a balance tank (7) (see Fig. 3.26). This ensures a constant flow rate to the process. A centrifugal pump (8) feeds the skimmed milk through a preheating section of the PHE (9). Although the addition of fat can suppress foaming in the skimmed milk, in this instance, a de-aerator vessel (10) is required. The milk base is preheated and homogenised in the manner described in Fig. 3.25, but then the milk flows through an in-line injector (13) where liquid fat from the fat-melting tank (11) is continuously metered into the flow by a positive displacement proportioning pump (12). Blending is completed in an in-line mixer (14) downstream of the injector. Immediately after mixing, the recombined milk continues to a high capacity homogeniser (15) and then returns to the PHE (9) for further processing as described in Fig. 3.13.

When dealing with the recombination of milk powder, two conditions in the reconstituted milk have to be monitored. First, not all the particles of milk may dissolve during the recombining process, perhaps through the use of poor quality powders, inefficient mixing equipment and/or the presence of scorched particles. Any undissolved particles must be removed using in-line stainless steel mesh, or a stainless steel mesh and nylon filter called the duplex, or centrifugal clarifiers. Clarifiers are excellent for the removal of any fine or undissolved particles and any

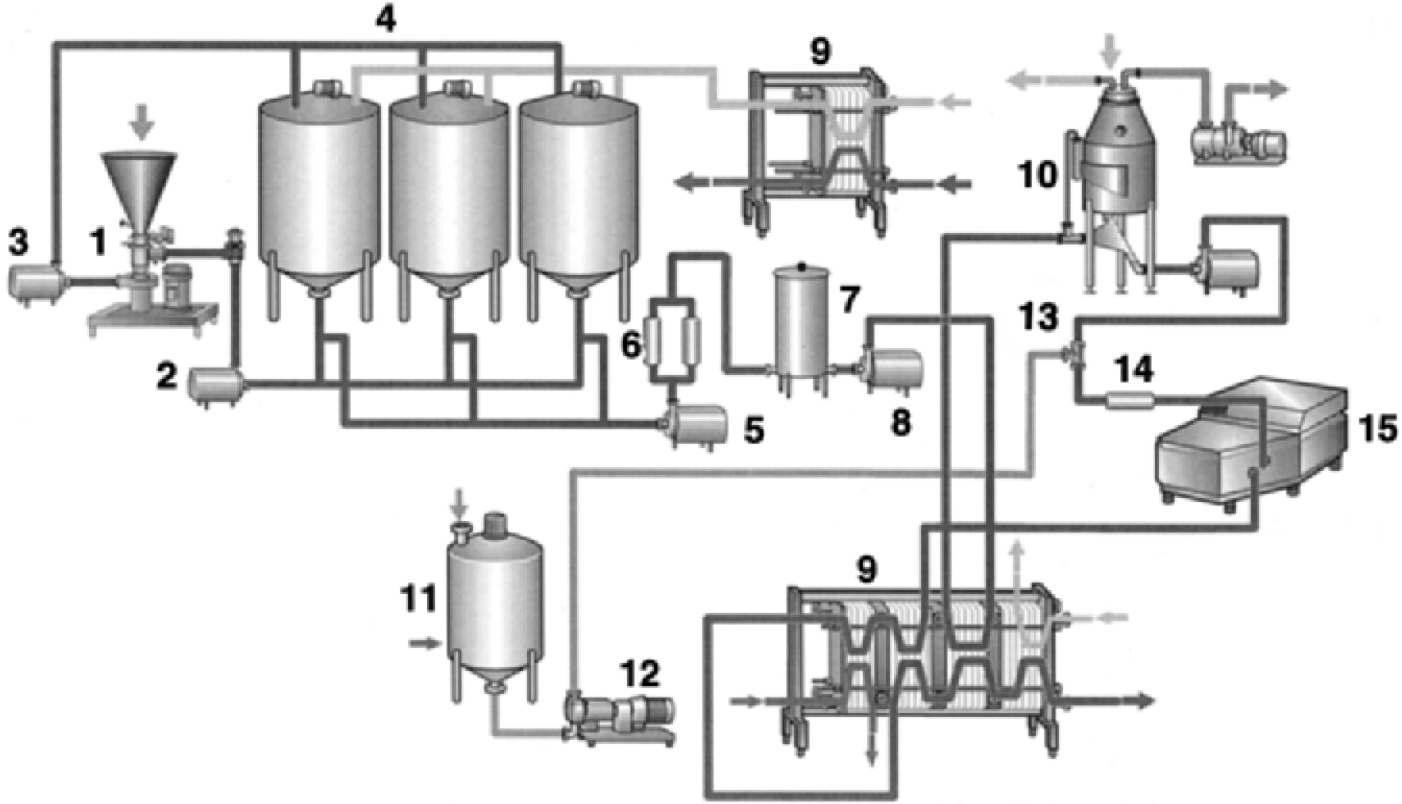

Fig. 3.26 Large-scale recombination plant with in-line fat mixing

1, Funnel with high-speed mixer (see Fig. 3.20); 2, pump for circulation; 3, booster pump; 4, mixing tanks; 5, discharge pump; 6, filters; 7, balance tank; 8, feed pump; 9, PHE; 10, vacuum de-aerator; 11, tank containing melted fat (e.g. cream or AMF); 12, positive displacement pump; 13, fat injector; 14, in-line mixer; 15, homogeniser.

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extraneous matter but, for convenience, filters are more commonly used. Normally two interchangeable filters are installed in a milk reconstitution line, especially in large dairies, so that in the case of clogging, the flow of milk can be easily diverted while one of the filters is being cleaned. The removal of such particles is essential, since their presence in the milk can damage the orifices in an homogeniser and/or increase soiling in heat exchangers. Second, reconstituted powders require up to 15 min to achieve complete hydration, otherwise sedimentation becomes evident. The hydration effect may not be important during the manufacture of yoghurt, since the time elapsing between recombination and the end of heat treatment of the milk can be as long as 15 min anyway.

3.3.3.3 Evaporation of milk

Concentration of standardised milk base can be achieved by use of an evaporator, in which the average amount of water removed is 10–25 g 100 g^{-1} and the total solids is increased by 1.5–3 g 100 g^{-1}, corresponding to the recommended fortification with milk powder (Bylund, 1995). In order to remove the desired amount of water and avoid damage to the milk constituents at high temperatures, the process of evaporation is normally carried out under vacuum.

Single-effect evaporators can be used directly in a yoghurt processing line. The milk base is pumped from the balance tank to the condenser where it is preheated and then enters the plate section of the evaporator for further heating. After reaching the preset temperature, the milk flows to the separator section and water vapour is removed from the milk; the cycle is repeated until the desired concentration of total solids in the milk base has been reached. Heat recovery during the evaporation process is very efficient and is achieved using a thermocompressor, that is, factory steam is mixed with the vapour produced from the evaporator.

Another type of single-effect evaporator which could be used to concentrate the milk base is supplied by Tetra Pak A/B. The sequence of operations is as follows. The standardised milk base is preheated to 70°C in the regeneration section of the PHE using the condensate from the evaporator (see Fig. 3.13). Subsequently the milk is heated to 85–90°C in the heating section of the PHE and the preheated milk enters the vacuum chamber where the inlet is shaped as an expansion tube to prevent burning of the milk. The milk is recirculated four to five times until the desired degree of concentration is achieved. The recirculation cycle is controlled by the capacity of the vacuum chamber, evacuation pump and the float controller; during each recycle, about 3–4 g 100 g^{-1} of water is removed. The capacity of such evaporators is up to 8000 l hour^{-1}, but for larger plants, different types of evaporators are used with capacities up to 30 000 l hour^{-1}.

In general these evaporators offer the advantages of minimum requirement for space, efficient heat recovery and immediacy of use. Furthermore, yoghurt made from milk concentrated in this way exhibits an excellent organoleptic quality.

3.3.3.4 Membrane concentration of milk

An alternative method of fortification of the milk base is by concentration of the milk (whole and/or skim) by membrane filtration (i.e. UF and RO). The basic differences between the UF and the RO systems are first that the operational pressures are much higher in the case of RO, and second that the RO membrane is less permeable than the UF membrane; the pore size for RO is <4 Å and for UF is >20 Å (1 mm = 10^7 Å; see Fig. 3.27).

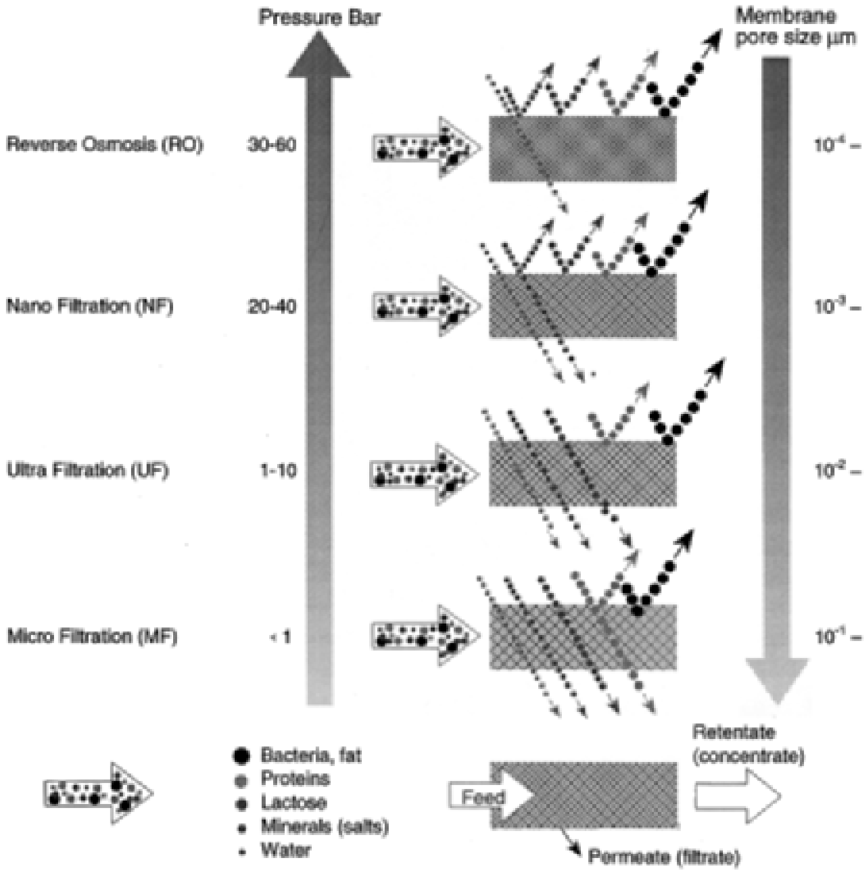

Fig. 3.27 Principles of membrane filtration systems of milk

Note: 10 Bar = 1 MPa; refer to Chapter 2 for milk constituent losses in the permeate. Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

The milk constituents that pass through a membrane are referred to as the permeate, and the material that does not pass through the membrane (i.e. concentrated fraction) is known as the retentate. The different components present in milk can be divided into three main groups based on the molecular weight, that is, large molecules (proteins and fats), medium (lactose and salts) and small (water). The RO membrane allows only the small molecules (water) to pass through the membrane and the retentate consists of a concentrate of all the milk constituents, while the UF membrane permits small and medium size molecular weight solutes (e.g. water, lactose and salts) to pass through; the retentate is a concentration of the macromolecules of proteins and fats. The differences in the composition of the permeate and the retentate of the RO and UF processes are illustrated in Fig. 3.27.

The application of membrane filtration in the yoghurt industry is most likely to involve the use of UF (see also Ottosen, 1988, 1990; Cheryan, 1998), since it has the advantage of giving an increased concentration of proteins, but a reduced level of lactose in the milk base. Recently, Lankes *et al.* (1998) reported that set and stirred yoghurts made from UF skimmed milk (16 g total solids (TS) 100 g^{-1}) had better gel

Fig. 3.28 View of an ultrafiltration plant which can be employed for yoghurt production
Reproduced by courtesy of APV Nordic, Denmark.

strength compared with yoghurt that had been fortified with SMP or concentrated by vacuum evaporator (VE). Figure 3.28 shows a UF plant in a dairy in Denmark being employed during the production of yoghurt.

3.3.4 Homogenisation

Homogenisers are used mainly for the purpose of providing stable fat-in-water emulsions so that the fat in the milk base does not separate, but homogenisation also brings about some desirable physical changes in the milk base which contribute towards:

- whiter and more attractive colour of the milk
- improved mouthfeel of the product
- increased viscosity.

The homogenisation process was invented by Gaulin in 1899 who described it as "fixer a composition des liquides" (Bylund, 1995). However, the primary action of the homogeniser is to cause disruption of the fat globules to give ones of smaller diameter. As a consequence, the homogenisation process diminishes the creaming effect of the milk fat and reduces the tendency of the fat globules to coalesce or clump. Such an effect is achieved by forcing full fat milk through a small passage at high velocity.

The theoretical concept of homogenisation has been reported by Bylund (1995), Anon. (1996c, d) and Pandolfe and Baekgaard (1997). At present, it is accepted that homogenisation reduces the fat globule size in the milk due to turbulence or cavitation. The former theory suggests that the energy dissipating in the liquid generates turbulent eddies. However, the intense energy of the turbulence and localised pressure differences then tear apart the droplets, reducing their average size.

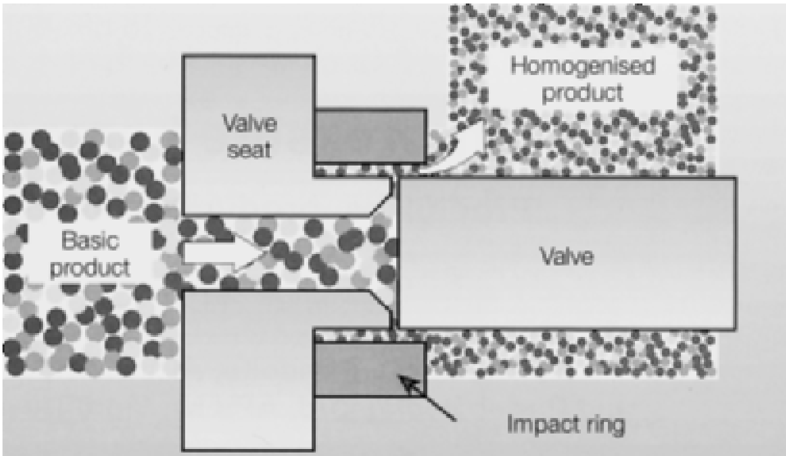

Fig. 3.29 Schematic diagram illustrating how the homogenising plug-type valve works
Reproduced by courtesy of APV Nordic, Denmark.

In the cavitation theory, the liquid encounters intense cavitation because of the large pressure drop through the valve. When the pressure drop is large enough, the vapour pressure of the liquid exceeds the ambient pressure causing the formation of vapour bubbles (cavities in the liquid). When the cavitation bubbles implode (collapse of the cavities), shock waves are generated in the liquid and these shock waves break apart the dispersed fat droplets. However, it has been suggested that some of the effects associated with turbulence and cavitation are similar, therefore making it difficult to distinguish clearly between the two (Anon., 1996c).

By tracing the path of flow of the full fat milk through the homogenising valve, it will be easier to understand the concept of homogenisation. However, many types of valve are available (see Harper *et al.*, 1976). Figure 3.29 shows a plug-type homogenising valve and a standard valve seat. The non-homogenised product enters the valve seat from the pump cylinder at a relatively low velocity (for example 3.1–6.1 $m s^{-1}$), but at high pressure (20.7 MPa). The pressure is generated by the positive displacement pump and the restriction to flow is caused by the valve being forced against the seat. Also, the positive displacement pump provides a relatively constant flow and, therefore, will generate the required pressures as the area between the valve and seat is increased or decreased. As the velocity of product flow between the valve and seat increases, the pressure decreases producing an instantaneous pressure drop. Then the liquid impinges on the impact or wear ring (see Fig. 3.29) and is finally discharged as an homogenised product.

High pressure homogenisers (see Fig. 3.30) are generally needed when high efficiency homogenisation is required. The product enters the pump block and is pressurised by the piston pump. The pressure that is achieved is determined by the back pressure given by the distance between the forcer and seat in the homogenisation device. This pressure, P1, is always designated the homogenisation pressure. P2 is the back pressure to the first stage or the inlet pressure to the second stage in two-stage homogenisers. The piston pump is driven by a powerful electric motor (Fig. 3.30 (1)) through a crankshaft and connecting-rod transmission which converts

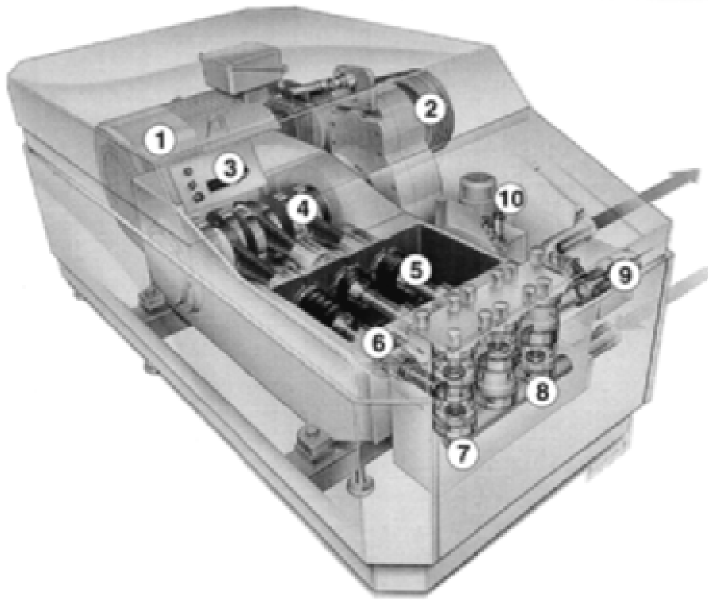

Fig. 3.30 View of a homogeniser which is a large high pressure pump with a back pressure device

1, Main drive motor; 2, V-belt transmission; 3, pressure indication; 4, crankcase; 5, piston; 6, piston seal cartridge; 7, solid stainless steel pump block; 8, valves; 9, homogenising device; 10, hydraulic pressure setting system.

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the rotary motion of the motor to the reciprocating motion of the pump pistons. The pistons (Fig. 3.30 (5)) run in cylinders in a high pressure block; they are made of highly wear-resistant materials. The machine is fitted with double piston seals and water is supplied to the space between the seals to cool the pistons. Hot condensate can also be supplied to prevent reinfection when the homogeniser is placed downstream in aseptic processes.

Milk is supplied at high pressure to the space between the seat and forcer. The width of the gap is about 0.1 mm or 100 times the size of the fat globules in homogenised milk. The velocity of the liquid is normally 100–400 $m\,s^{-1}$ in the narrow annular gap and homogenisation takes place in 10–15 μs. During this time, all the pressure energy delivered by the piston pump is converted to kinetic energy. Part of this energy is converted back to pressure again later and the other part is released as heat. Every 4 MPa drop in pressure across the gap gives a temperature rise of 1°C. In fact, less than 1% of the energy is utilised for actual homogenisation but, nevertheless, high pressure remains the most efficient method available to handle emulsions.

With regard to the impact of homogenisation of the milk base on the quality of yoghurt, a number of aspects have to be considered (see also Hong, 1995), for example, the use of single- or two-stage homogenisation and the positioning of the homogeniser (i.e. before or after heat treatment). Since most of the yoghurts produced in different countries of the world contain fat ≤3.0 g 100 g^{-1}, it is arguable

whether two-stage homogenisation is necessary. Kessler (1998) has examined a number of factors that can influence the firmness of yoghurt made from a milk base containing 10 g fat 100 g^{-1} and his findings can be briefly summarised as follows:

- Use a mixture of 50:50 WPC and SMP instead of SMP alone.
- Denature β-Lg to ≥90% (for more information refer to Chapter 2) or heat treat the milk base at high temperatures, e.g. 95°C for 80 s.
- Increase the single-stage homogenisation pressure to 30 MPa; however, circulating the milk with up to four passes through the single-stage homogeniser at 20 MPa increased the firmness of the gel, or reduction of the fat globule diameter from 1.8 μm to 1.1 μm resulted in a doubling of the firmness of the product.
- Homogenisation of the milk base after the heat treatment stage produces a firmer product because the homogeniser causes the casein micelles to be torn apart by surface-active forces while new fat globules are being formed; during acidification, hydrophobic interactions result in a more stable protein network.

3.3.5 Heat treatment

The purpose of the heat treatment of the milk base has been discussed in detail in Chapter 2, and hence only the important technical aspects will be reviewed in this section (see also Klupsch, 1984, 1985; Lucey *et al.*, 1998; Kessler, 1998).

The heating of the milk base and the cooling of the coagulum both involve one fundamental aspect of thermodynamics, heat transfer (Hall, 1976; Loncin and Merson, 1979; Kessler, 1981, 1998; Hall *et al.*, 1986; Fikiin *et al.*, 1987; Brennan *et al.*, 1990; Bylund, 1995; Fryer *et al.*, 1997). In general, the flow of heat takes place from a warmer medium to a cooler and the greater the temperature differential between the two media, the greater and/or more rapid the heat flow. This transfer of heat can be either by conduction, convection or radiation (see Table 3.1) but, in the dairy industry, the former two processes are more important. The actual application of heat may be carried out in a direct or indirect manner but, for practical reasons, the latter is most widely used. Thus, instead of steam (food grade) being injected into the milk during the heating stage, the heating medium and the milk never come into contact with each other; the chemical composition of the milk base remains unaltered during the heat treatment. Similarly, the indirect method of heat transfer is used for cooling the coagulum.

The types of equipment that can be employed for heat treatment of milk include:

- The batch process (batch pasteurisers or multipurpose tanks) in which the milk can be heated by direct steam injection into the milk, or indirectly by one of the following methods: (a) steam injection into the jacket (this system allows excellent heat transfer, but may lead to severe denaturation of the milk due to localised heating), and (b) steam injection into the water jacket (this system of heating is widely used); alternatively, the water can be heated by gas or electricity and such processing tanks are very popular with the small-scale producers.
- The continuous process (plate, tubular or scraped surface heat exchangers) in which the milk is heated by the indirect method using either direct steam (under reduced pressure) in the heating section of the heat exchanger or alternatively hot water.

The types of equipment used for heating the milk base are as follows.

Table 3.1 Brief definition of types of heat transfer and factors affecting thermal conductivity

Types of heat transfer	Factors affecting thermal conductivity
Conduction is the transfer of thermal energy from one molecule to another and this may take place through solid bodies or through layers of liquid at rest in which no physical flow or mixing takes place in the direction of heat transfer.	• Area • Thickness or length of heat transfer path • Temperature difference
Convection is the transfer of thermal energy due to the movement of mass and this occurs when particles at high temperatures are mixed with particles at a lower temperature.	• As above • Movement of fluid • Fluid characteristics (thickness, viscosity, turbulence, velocity and temperature of fluid)
Radiation is the emission of thermal energy by radiation (hot or cold) across an absolute vacuum in which the electromagnetic radiation of a body causes molecules to vibrate and emit radiant energy.	• Surface property of the body • Temperature of the body } e.g. a black body shows good absorbance and emission of heat

3.3.5.1 Batch or multipurpose tanks

These tanks resemble batch pasteurisers and they are normally water jacketed. Steam is injected into the water during the heating stage of the yoghurt milk and chilled water is circulated during the cooling of the coagulum. The capacity of these tanks is several thousand litres, and according to Kessler (1981) the time required to heat the milk base with vigorous stirring can be calculated from the following equation:

$$\text{Time of heating} = \frac{\text{Volume (m}^3) \times \text{Density (kg m}^{-3}) \times \text{Specific heat (J kg}^{-1}\text{K}^{-1})}{\text{Effective heat exchange area (m}^2) \times \text{Heat transfer coeffient (W m}^{-2}\text{K}^{-1})} \times \ln \frac{\text{Temperature of heated medium} - \text{Starting temperature of the milk base}}{\text{Temperature of heated medium} - \text{Desired temperature required to heat the milk base}}$$

$\ln = \text{natural logarithm}$

In a large processing plant, a series of these tanks could be used at regular intervals for the production of yoghurt on a semi-continuous basis. A typical processing cycle using multipurpose tanks could involve the following stages:

- filling the tank with fortified and homogenised milk at ≥60°C;
- heating the milk base to 85–90°C for 15–30 min;
- cooling the milk to the incubation temperature, i.e. 40–45°C (short set) or to 30°C (long set);
- incubating the milk to the desired acidity;
- cooling the coagulum to 20°C or <10°C.

Examples of multipurpose yoghurt processing tanks have been reviewed by Tamime and Greig (1979) and Robinson and Tamime (1990, 1993) and the design of such tanks should cover the following aspects:

- Provision of a heat exchange medium (e.g. direct steam or hot water) for circulation in the jacket and high speed agitation for use during heating of the milk.
- For in-tank cooling (optional, refer to subsequent text), glycol or chilled water is circulated in the jacket and slow speed agitation must be provided during the cooling of the coagulum.
- These tanks usually have a conical base to facilitate easy emptying of the cooled yoghurt.

3.3.5.2 Continuous process

The types of heat exchangers most commonly used in the dairy industry are:

- plate heat exchanger (PHE)
- tubular heat exchanger, including the multitube or multichannel designs
- scraped/swept surface heat exchanger.

The former two types are widely installed in yoghurt plants for the heat treatment of the milk base, but the swept surface heat exchanger is used for the heat treatment of fruit preparations. These heat exchangers can be visualised as two-channel units in which the heating medium (hot water) flows in one channel and is separated by a partition from the yoghurt milk flowing in the other (Bylund, 1995; Anon., 1996e). The milk is processed, therefore, on a continuous basis and, when compared with the batch process systems, offers the following advantages: (a) a small floor area is required, (b) less energy is required due to the improved efficiency of heat transfer and heat recovery; (c) productivity can be increased by utilising the fermentation tanks more than once per day, and (d) the system is more versatile, for example the processed milk could be removed from the plant at a certain temperature to be homogenised.

A PHE is a unit which consists of a series of corrugated stainless steel plates held together in a frame and a rubber gasket is fitted to prevent leakage between the milk and water passages along the boundaries between the plates. The corrugation of the plate helps to increase the turbulence of the liquid flow and/or the surface area of the plate and hence improve the efficiency of heat transfer. Also, the shape of the partition in a PHE may differ depending on the product to be treated and thermal efficiency requirements. The thickness of the gasket does, of course, alter the space between the plates, and while a narrow gap is desirable for the heat treatment of milk (e.g. 2.5 mm), a larger gap (e.g. up to 6 mm) is recommended for cooling of the coagulum. In the former instance, the milk flows in a thin film across the width of the plate, so that heat transfer is rapid, but the large gap is necessary during the cooling of the yoghurt in order to avoid too great a drop in viscosity.

According to Bylund (1995), the necessary size and configuration of any type of heat exchanger are governed by multitude of factors such as:

- product flow rate
- physical properties of the liquids to be processed
- temperature programme
- permitted pressure drops
- heat exchanger design
- cleaning requirements
- required running or operation time.

Thus, the general formula, which is used to calculate the required heat transfer area of a heat exchanger, is

$$A = \frac{V \times \rho \times c_p \times \Delta t}{\Delta t_m \times k}$$

where A is the required heat transfer area, V is the product flow rate, ρ is the density of the product, c_p is the specific heat of the product, Δt is the temperature change of the product, Δt_m is the logarithmic mean temperature difference (LMTD) and k is the overall heat transfer coefficient.

In practice, a PHE consists of several sections in which different treatments of the milk may take place, for example, preheating/regeneration, final heating, holding and/or cooling sections. The heating medium is normally hot water, but if the milk is to be heated to temperatures above 100°C, steam (under reduced pressure) may be used. The cooling medium can be cold water, chilled water or brine, and the type of coolant circulated in a PHE is dependent on the desired outlet temperature of the product.

The flow of both milk and heating/cooling medium in a PHE can run alternately (i.e. single-channel operation), but the efficiency of heat transfer is difficult to maintain. To overcome this disadvantage, the flow of fluids in a PHE may be arranged into special patterns, and one example has a combination of a $4 \times 2 / 2 \times 4$ (Bylund, 1995). Such a combination means that the heating medium is in four parallel channels and changes its direction twice, and the flow of milk is in two parallel channels and changes direction four times.

The tubular heat exchanger is, as the name indicates, constructed from tubes or pipes and may be in the form of a single-tube heat exchanger, or may consist of a bundle of tubes or multichannel tubes. In a single-tube type, the heat exchanger consists of one tube inside another (heating/cooling medium) tube (coaxial double tube), but if a larger surface area is required, the product/medium tubes can be arranged spirally within an upright cylindrical tank. This latter type of a heat exchanger is manufactured by Stork-Amsterdam. The flow of liquids in this unit can be either parallel or counter current, and the latter is usually recommended for the heat treatment of the milk base. A more recent development is a multichannel tubular heat exchanger in which a number of coaxial tubes are fitted inside each other; the heating medium flows in the spaces of these tubes and the milk flows through the middle of each tube. In the other type of tubular heat exchanger, bundles of tubes are enclosed within an outer shell and while the milk flows through the pipes, the heating/cooling medium circulates inside the shell.

For the heat treatment of viscous products the scraped/swept surface heat type is used and the unit consists of a jacketed cylinder fitted with a scraper blade. The blades, which rotate at a high speed, remove the continuously processed product from the heated surface and, as a result, the effective surface area is large; heat trans-

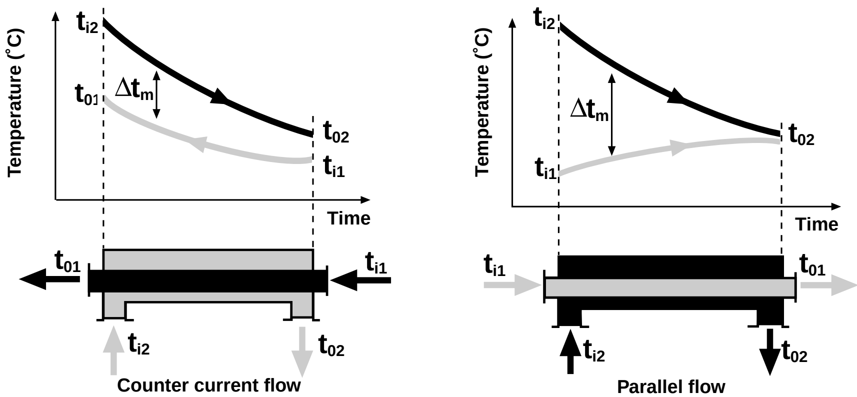

Fig. 3.31 Differences in the temperature profiles for heat transfer in a PHE either with parallel or counter-current flow

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fer is normally rapid, depending on the speed of rotation of the blades. These heat exchangers can be mounted vertically or horizontally.

In principle, irrespective of what type of heat exchanger is used, it is safe to assume that heat transfer through a partition wall resembles the profile illustrated by Bylund (1995). The flow of fluids (i.e. hot water and milk) in a heat exchanger can be either in the same direction (parallel flow) or in the opposite direction (counter-current flow) and, in each situation, the profile of temperature changes during the heat treatment of milk is different (see Fig. 3.31). In counter current flow, the milk and the heating medium enter the heat exchanger from opposite ends (i.e. the cold milk meets the cooled heating medium) and the temperature is progressively raised as it passes through the heat exchanger. The overall temperature of the heated milk is always a few degrees below the temperature of the heating medium at the corresponding point (see Fig. 3.31). However, in parallel flow, both the milk and the heating medium enter the heat exchanger from the same end and, as a result, the increase in temperature of the product is never higher than if the milk and the hot water were mixed together (see Fig. 3.31). Different efficiencies of heat transfer are, therefore, obtained from the contrasted types of flow and Kessler (1981) reported a 50% maximum efficiency for parallel flow; the efficiency was much higher with the counter-current system.

As mentioned earlier, the equipment for continuous heat processing is made up from different sections. In a plant designed for the heat treatment of the milk base, these sections are:

- regeneration section
- heating/cooling section
- holding unit.

It is also important that the plant is installed with a balance tank in order to maintain a continuous flow of milk. Balance tanks are normally situated in the area where the milk is being fortified and/or standardised. Different types of balance tank are available on the market, fitted either with a special float or with level sensors that ensure that milk is always available.

Regeneration section – In this section the incoming cold yoghurt milk is prewarmed by the heated milk and vice versa, with the aim of utilising energy more efficiently and economically. For example, if the temperature of the milk base is raised from 5°C to 90°C (hot water) and then cooled to 40–45°C (cold water), the energy demand is high; energy is required to heat the hot water and also to cool the cold water. However, if the heat energy can be utilised in the regeneration sections of the plant, the result is energy conservation and the efficiency of regeneration is sometimes expressed as a percentage. Fearn (personal communication) has provided the following energy data relating to two different types of Tetra Pak yoghurt processing plants.

In the first example the capacity of the plant was 4000 l hour^{-1} and the milk base was fortified by the addition of SMP. The temperature progression using a plate heat exchanger fitted with a regeneration section was as follows:

- The temperature of the milk base was raised from 5°C to 45°C by regeneration, i.e. utilising the heat from the already heated milk, and the temperature change was 40°C. The prewarmed milk was heated from 45°C to 90°C by hot water (incidentally, at around 60–70°C the milk left the heat exchanger to be homogenised before returning to the plant for final heating).
- The heated milk was cooled from 90°C to 50°C by regeneration, i.e. transferring the energy to the incoming cold milk, and the temperature change was 40°C.
- The partially cooled milk at 50°C was further cooled to 40–45°C (incubation temperature) by water.

It can be observed that the milk base was heated from 5°C to 90°C (a temperature increase of 85°C) and that the increase in the regeneration section was 40°C. Therefore, according to Bylund (1995), the percentage of regeneration calculated from the following formula was equal to:

$$R = \frac{(t_r - t_i)}{(t_p - t_i)} \times 100$$

where R is the regeneration efficiency %, t_r is the milk temperature after regeneration (45°C), t_i is the temperature of raw incoming milk (5°C), t_p is the temperature after heat treatment (90°C),

$$R = \frac{(45 - 5)}{(90 - 5)} \times 100 = \frac{40}{85} \times 100 = 47\%$$

Although this figure is relatively low compared with a normal pasteuriser HTST (high temperature short time) or ultra high temperature (UHT) plants which may be about 94% efficient, the contrast is due to the fact that the product outlet temperature in the case of HTST and UHT milks is around 5°C and 20°C, respectively, compared with the milk base at 40–45°C. Thus, the energy requirements of the 4000 l hour^{-1} plant are 325 kg hour^{-1} of steam and 4000 l hour^{-1} of water.

In the second example the same capacity plant (4000 l hour^{-1}) was used for heat treatment of the milk base, but the plant was installed with a single-effect evaporator to concentrate the milk to the desired level of solids (see Fig. 3.13). The temperature progression was as follows:

- The incoming cold milk was prewarmed from 5°C to 60°C by regeneration, i.e. utilising the energy available in the condensate from the evaporator.

- The partially heated milk at 60°C was then heated by hot water to 90°C before entering the evaporator (in order to achieve the correct concentration of solids in the milk base, the milk was circulated within the evaporator and the heating section of heat exchanger at a flow rate of 19000 l hour^{-1}).
- The concentrated milk left the evaporator at 70°C and was homogenised; later it was heated to 82°C by regeneration, i.e. utilising the energy available from already heated milk.
- The concentrated milk at 82°C was heated to 90°C with hot water.
- The heated milk base was cooled from 90°C to 78°C by regeneration, i.e. a transfer of energy to the concentrated milk at 70°C.
- The milk base was then cooled from 78°C to 40–45°C (e.g. the incubation temperature) by cold water.

To calculate the percentage regeneration of this system is more complicated than with the first example, and the simplest approach is to divide the overall thermal load by the amount of heat obtained from regeneration which when multiplied by 100 is equal to the percentage regeneration. If the specific heat and the density of the milk base are assumed to be the same as water, that is 1, the calculations are as follows:

- 5–60°C (regeneration) – heat obtained is 55 × 4700 = 258500 kcal hour^{-1}
- 60–90°C (hot water) – thermal load is 30 × 19700 = 591000 kcal hour^{-1}
- 70–82°C (regeneration) – heat obtained is 12 × 4000 = 48000 kcal hour^{-1}
- 82–90°C (hot water) – thermal load is 8 × 4000 = 32000 kcal hour^{-1}

Therefore the overall thermal load is:

- 258500 + 591000 + 48000 + 32000 = 929500 kcal hour^{-1}

The heat obtained by regeneration is:

- 258500 + 48000 = 306500 kcal hour^{-1}

The percentage of regeneration is:

- $\frac{306\,500}{929\,500} \times 100 = \sim 33\%$

Thus, the energy requirements of such a plant are 840 kg hour^{-1} of steam and 9200 l hour^{-1} of water.

Although the percentage regeneration in the second example is slightly lower than in the former case, two factors must not be overlooked, the cost of the SMP and the quality of yoghurt produced from concentrated milk. The latter aspect has already been illustrated in Fig. 2.13 (see Chapter 2).

Heating section – In this part of the heat exchanger, the milk base is heated to the desired temperature and under commercial practice the final temperature may range from 85 to 115°C.

Holding section – The holding section of a heat exchanger is that part of the plant in which the heated milk can be maintained at temperature for a specified period of time. The objective is to provide for those time–temperature relationships that comply with existing legislation, for example pasteurised milk (HTST) must be heated to 72°C and held at that temperature for 15 s. There are, of course, no regulations regarding the heat treatment of the milk base for yoghurt, so in practice the time–temperature combination is chosen both to ensure the destruction of

pathogens and to bring about the physicochemical changes desired in the milk (refer to Chapter 2).

In the holding section no heating or cooling of the milk takes place and depending on the holding time desired, the unit can be built either as part of the heat exchanger or as a separate unit on its own.

Different time–temperature relationships have been employed for the heat treatment of the milk base and some examples of these combinations are:

- 30 min at 85°C (long holding time)
- 5 min at 90–95°C (medium holding time)
- 3 s at 115°C (short holding time).

It is evident, however, that the holding section of a yoghurt processing plant will, in most cases, have to be built as an external unit linked to the heat exchanger. The equipment available for holding milk for the specified times includes:

- Holding for "long time" – in order to provide a 30 min holding time in a continuous processing plant, a well-insulated or water-jacketed tank can be used instead of the usual holding unit. This method of holding requires a large floor area, but was widely used in the yoghurt industry in 1980s. At present, the long time holding system is rarely used in large yoghurt plants.
- Holding for "medium time" – spiral or zig-zag arrangements of pipework are often used as holding units for up to 5–6 min, and two typical examples are: the Tetra Pak (Fig. 3.32) or APV holding tube which is constructed from two spirals of stainless steel pipe enclosed in an insulated, upright cylindrical tank; a modified version, in which a 6 min holding time can be achieved, has been designed with large diameter zig-zag piping (see Robinson and Tamime, 1993).
- Holding for "short time" – in this case the holding section can be incorporated into the heat exchanger but, if a larger capacity of holding unit is required, the pipe can be installed outside the plant.

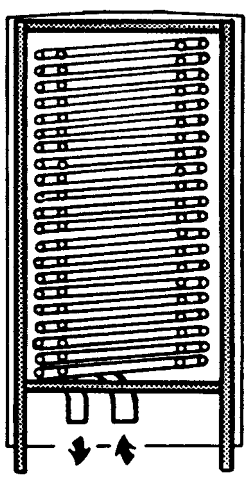

Fig. 3.32 Schematic illustration of holding tube/cell for medium time treatments up to 5 min

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The appropriate tube length for the required holding time can be calculated when the hourly capacity and the inner diameter of the holding tube are known (Bylund, 1995). As the velocity profile in the holding tube is not uniform, some milk molecules will move faster than average. To ensure that even the fastest molecule is sufficiently pasteurised, an efficiency factor must be used. This factor depends on the design of the holding tube, but is often in the range of 0.8–0.9. The formulae required for the calculations are:

$$V = \frac{Q \times HT}{3600 \times \eta} \text{dm}^3$$

$$L = \frac{V \times 4}{\pi \times D^2} \text{dm}$$

where Q is the flow rate at pasteurisation (l hour^{-1}), HT is the holding time in s, L is the length of holding tube in dm, corresponding to Q and HT, D is the inner diameter of holding tube in dm, to be known or adapted to the other pipework, V is the volume of milk in litres or dm^3 corresponding to Q and HT, η is the efficiency factor and π is 3.14.

For example, a holding time (HT) of 15 s is required in a pasteurisation plant with a capacity (Q) of 10000 l hour^{-1}. The inner diameter (D) of the pipe to be used is 48.5 mm – 0.485 dm. Calculate the length (L) of the holding tube, with an efficiency factor of 0.85.

$$V = \frac{10\ 000 \times 15}{3600 \times 0.85} = 49.0 \text{ dm}^3$$

$$L = \frac{49.0 \times 4}{\pi \times 0.485^2} = 265.5 \text{ dm or } 26.5 \text{ m}$$

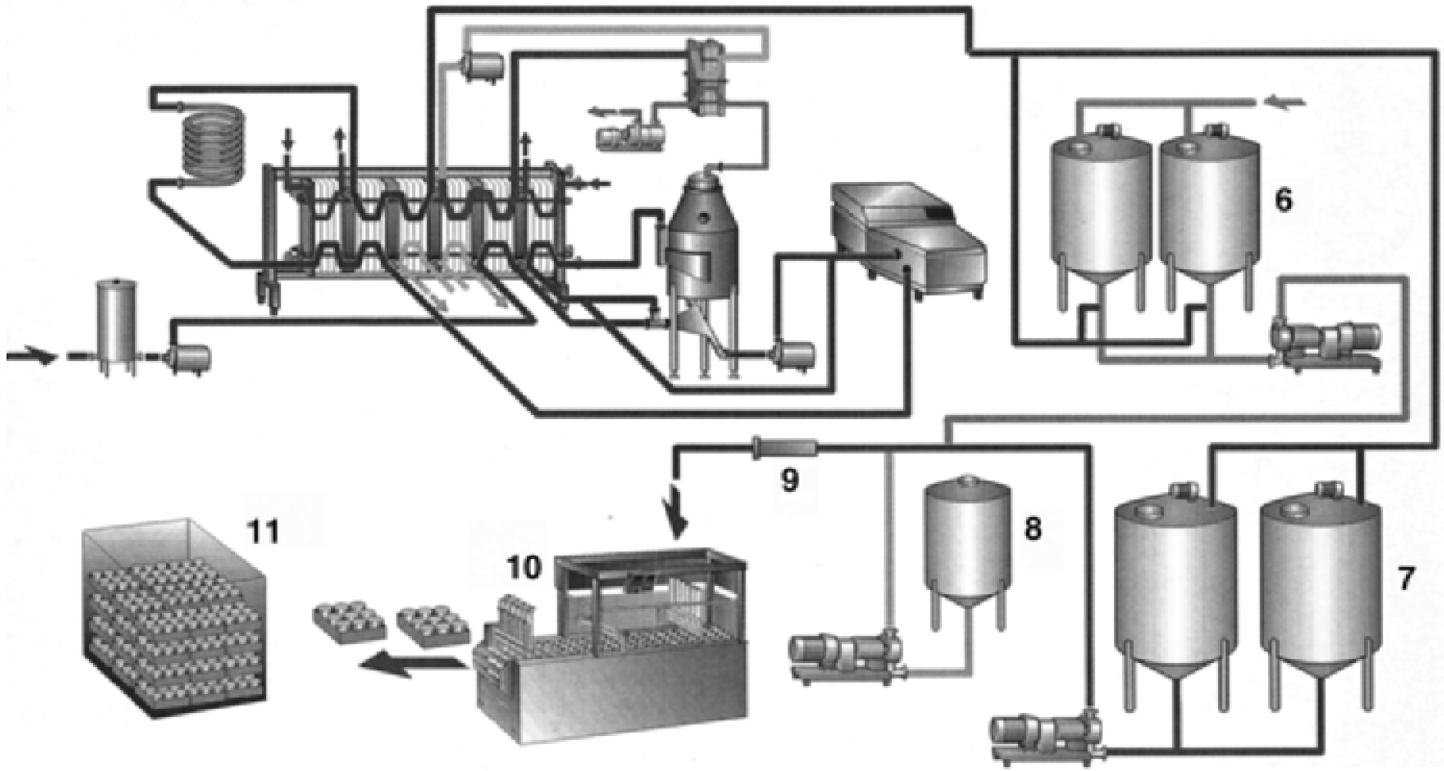
Thus, the length of the holding tube should be about 26.5 m.

Heat processing plants (e.g. for HTST and UHT milks) are fitted with a temperature-sensor safety device known as flow diversion valve (FDV). At the start of the processing operation the milk is normally diverted back to the balance tank until the right temperature is achieved and maintained, and only then does the milk flow through the rest of the plant to complete the processing cycle. However, the milk is always diverted back to the balance tank at any time that the temperature drops, so making sure that all the processed milk is heat treated to the specified temperature. The FDV unit is not, however, normally installed in a yoghurt plant, for if the temperature of the heated milk starts to drop, manual diversion of the milk back to the balance tank via a special arrangement of pipes is quite acceptable.

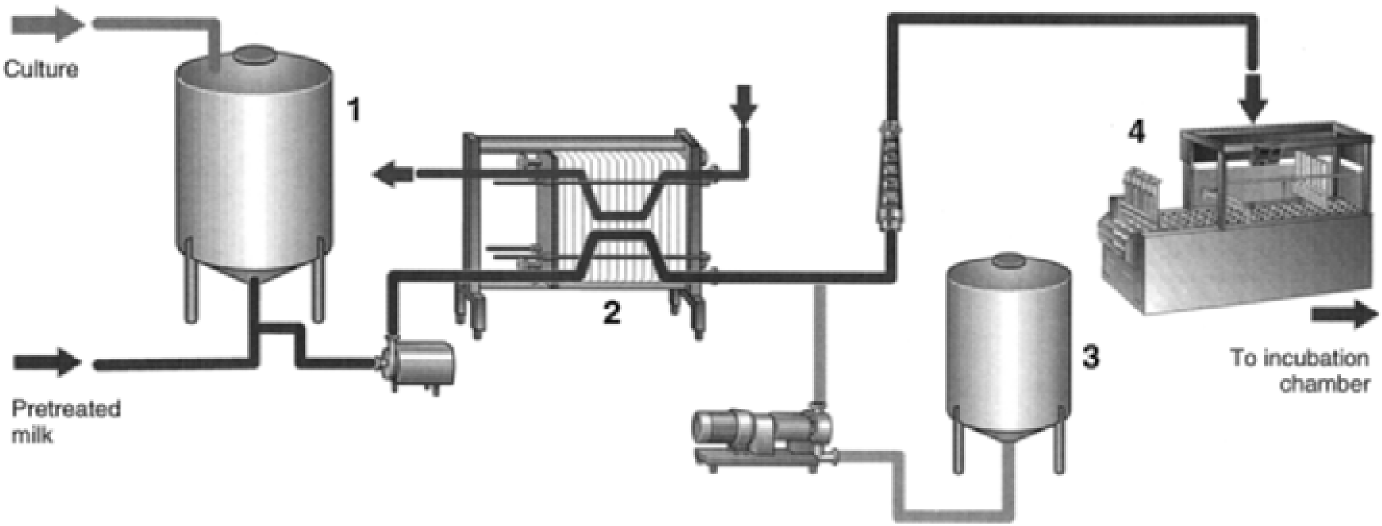
Normally, at the start of the heat treatment process, water is circulated through the plant both to sanitise the pipework and to warm the plant to the desired processing temperatures. Warming the plant avoids prolonged circulation of the initial milk intake.

3.3.6 Fermentation/incubation of the milk

At this stage of yoghurt manufacture, the processed milk (i.e. standardised/fortified, homogenised and heated milk) is cooled to the incubation temperature, which would be in the range of 40–45°C (short fermentation: $2\frac{1}{2}$–3 hours) or 30°C (long fermentation: overnight) and there are many different types of fermentation vessel



(A)



(B)

Fig. 3.33 Production lines for set yoghurt

A: Details of pretreatment of the milk base are given in Fig. 3.13; 6, bulk starter tanks; 7, buffer tanks; 8, flavouring tank; 9, in-line mixer; 10, filling machine; 11, incubation (see text). B: 1, Buffer tank; 2, PHE; 3, flavouring tank; 4, filling machine.

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which can be used. Basically the equipment is designed to provide and maintain the necessary processing condition(s), especially temperature and the form of the equipment depends on the type of yoghurt produced, that is, set or stirred.

3.3.6.1 Equipment for the production of set yoghurt

The fermentation/coagulation of the milk base takes place in the retail container. In brief, the process may involve the following stages:

- Cool the processed milk base to 40–45°C or 30°C.
- Add the starter culture and, if desired, flavouring materials and/or colouring matter to the milk. Incidentally, for the production of fruit set yoghurt (sundae style), the fruit is delivered into the retail container followed by the inoculated milk.
- Seal the retail containers, incubate, cool and dispatch.

It is evident that the same plant that processes the milk base (see Fig. 3.13) can be used for the production of both set and stirred yoghurt and, as a consequence, the installation costs can be reduced. An overall illustration of the plant is shown in Fig. 3.33A (Bylund, 1995). The starter culture is metered into the processed milk base (at the correct temperature) as it is pumped from an intermediate/buffer storage tank to the packaging machine. Also, the flavouring(s) can be continuously metered into the milk stream prior to packaging. As mentioned earlier, fruit pieces and other additives should be dosed into the yoghurt cups before they are filled with the inoculated milk.

Since the daily production of set yoghurt may be small, an alternative production system may be used (see Fig. 3.33B) which offers flexibility in production planning because the size of plant does not necessarily have to match the pretreatment capacity of the milk base or the capacity of the filling machines. The processed milk is cooled to <10°C and thoroughly mixed with the starter culture (e.g. DVI type). Matching the capacity of the selected machine, the milk/starter mixture is warmed in a PHE to the incubation temperature, mixed with flavours and finally packaged. Alternatively, bulk starter culture can be metered in-line to the warmed milk at the same time as the flavours (Bylund, 1995).

The correct conditions for fermentation are provided by employing one of the following approaches.

Water baths or tanks – In this system, the yoghurt containers, which are often glass bottles, are placed in metal trays immersed in shallow tanks of warm water; details of this old method were reported by Crawford (1962). The water level is maintained just below the tops of the bottles to avoid contamination of the product and, after the coagulation period, the warm water is replaced by circulating cold water that cools the coagulum very quickly. When the yoghurt is partially cooled, the trays are removed and transferred to the refrigerated store for final chilling. Since this method necessitates the use of glass bottles, the use of water baths/tanks is of limited popularity.

Cabinets – In the cabinet system, incubation takes place in small insulated chambers with average capacities ranging from 250 to 750 l. Forced hot air is circulated during the fermentation stage and later it is replaced by chilled air. In order to improve the heat transfer characteristics of these units, the cabinet has the facility to moisten the hot air; if the retail container is moisture sensitive, then hot dry air is recommended.

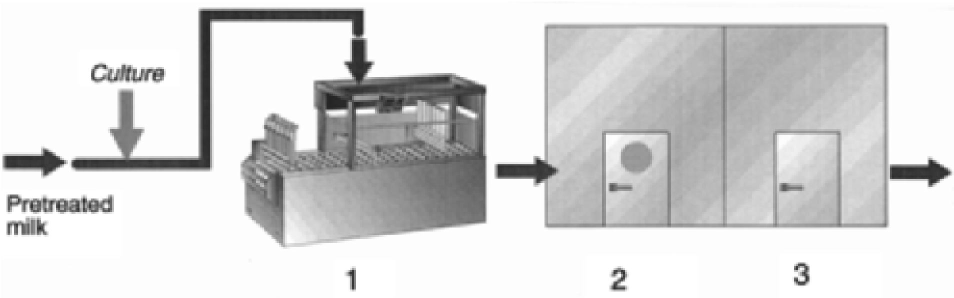

Fig. 3.34 Illustration of set yoghurt production showing incubation and rapid cooling rooms

1, Filling machine; 2, incubation cabinet; 3, rapid cooling room.

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Rapid cooling at the end of the fermentation stage is achieved by circulating chilled air. The yoghurt is then left until dispatched or, when the product temperature is low enough, moved to the main cold store. All units of this type are electrically operated and some incubator/cooler cabinets are fitted with a pH controller so that the fermentation/cooling cycle can be automated; in many cases the processing cycle is worked on a time basis. Nevertheless, the production of a uniform yoghurt does necessitate attention to the following points:

- The cabinets must be relatively small in size, so that the pallets can be stacked very quickly; the time lag between the first and the last yoghurt containers being placed in the cabinet should be very short.
- The air must circulate uniformly to all parts of the cabinet.
- There must be provision for accurate and reliable temperature control in the cabinet.

In some instances the cabinets are used only as incubators and the yoghurt is cooled in another cabinet (Fig. 3.34) or a refrigerated cold store. The disadvantage of this approach is that the coagulum is in motion while it is still warm and hence may suffer some structural damage and/or whey separation. However, the system may be less expensive to install in the first instance.

Tunnel – Large quantities of set yoghurt could be produced in batteries of individual cabinets, but the process can be mechanised for continuous production by adopting a tunnel system; however, it should be emphasised at this stage that the concept of continuous yoghurt production is different. For further details refer to Section 3.5. The pallets containing the yoghurt pots are placed on smooth rollers/conveyor belt and travel through a tunnel consisting of two sections. Warm air is circulated in the incubation part of the tunnel and the speed of the pallet is governed by the speed of the conveyor belt, which in turn is regulated by the rate of lactic acid production in the milk. At the end of the fermentation period, which is equivalent to pH 4.5, the pallets pass through the cooling section and the hot air is replaced by a blast of chilled air. The yoghurt is partially cooled in this section and final cooling takes place in the cold store. Since the yoghurt is in motion during the incubation/cooling periods, extreme care must be exercised to avoid damage to the coagulum.

Table 3.2 Different systems of incubators/coolers used for the manufacture of set yoghurt

	Waterbath tanks	Cabinet	Tunnel
Incubation/cooling in the same compartment	Yes	Yes/alternatively cabinets may be used only as incubators and then pallets removed and cooled in cold store	The first part of the tunnel is the incubator and the final section is used as a blast cooler
Heating and cooling agent	Water	Air	Air
System of production	Batch[a]	Batch[a]	Continuous
Packaging material	Glass	Glass, cartons or plastic	Glass, cartons or plastic
Variation in the quality of yoghurt	Yes[b]	Yes[b]	Slightly
Energy consumption	High	High	Low
Processing floor area	Large	Medium	Small

[a] Semi-continuous production line can be achieved if water tanks or cabinets are in series. [b] If filling time of pallets exceeds 15 min.

After Tamime and Grieg (1979). Reprinted with permission of *Dairy Industries International*.

A combined system for the production of set yoghurt consisting of incubation rooms and a cooling tunnel is used at the S.V. Inza Co-operative in Belgium (Cottenie, 1978). The advantage of this approach may be that, while the yoghurt cups are not in motion during the incubation period, the cooling rate of yoghurt containers in a tunnel is much faster than can be achieved with other methods. Thus, in practice the milk is acidified to pH 4.5 in the incubation room and then transported to the cooling tunnel where the temperature of the yoghurt reaches 10°C in around $1\frac{1}{2}$ hour (see also Kessler and Bäurle, 1980; Kessler, 1981, Anon., 1983b). Incidentally, the cooling tunnel is connected directly to the cold store so that the palletised cups of yoghurt can be transferred easily using a forklift truck.

The different systems used for the manufacture of set yoghurt have been evaluated by Cottenie (1978), and a summary of their main features is shown in Table 3.2. The conclusion emerges that, while the water bath system was at one time popular in Europe for the production of set yoghurt, the present trend is to use cabinets for medium-size production runs and the tunnel system for more extensive batches.

An update of the tunnel system has been reported by Bylund (1995) (Fig. 3.35). The filled packages/containers of inoculated milk are placed in crates of open design and at a certain distance from each other so that the circulating warm/cold air for the incubation and cooling stages can reach every individual container and provide accurate temperature control. When the empirically determined optimum pH (typically 4.5) is reached, it is time to start cooling. The normal target temperature is 18–20°C; it is important to stop further growth quickly, which means that a temperature of about 35°C should be reached within 30 min, and 18–20°C after a further 30–40 min.

Final cooling, normally down to 5°C, takes place in the chill store, where the products are held to await distribution. Cooling efficiency depends on the size of the

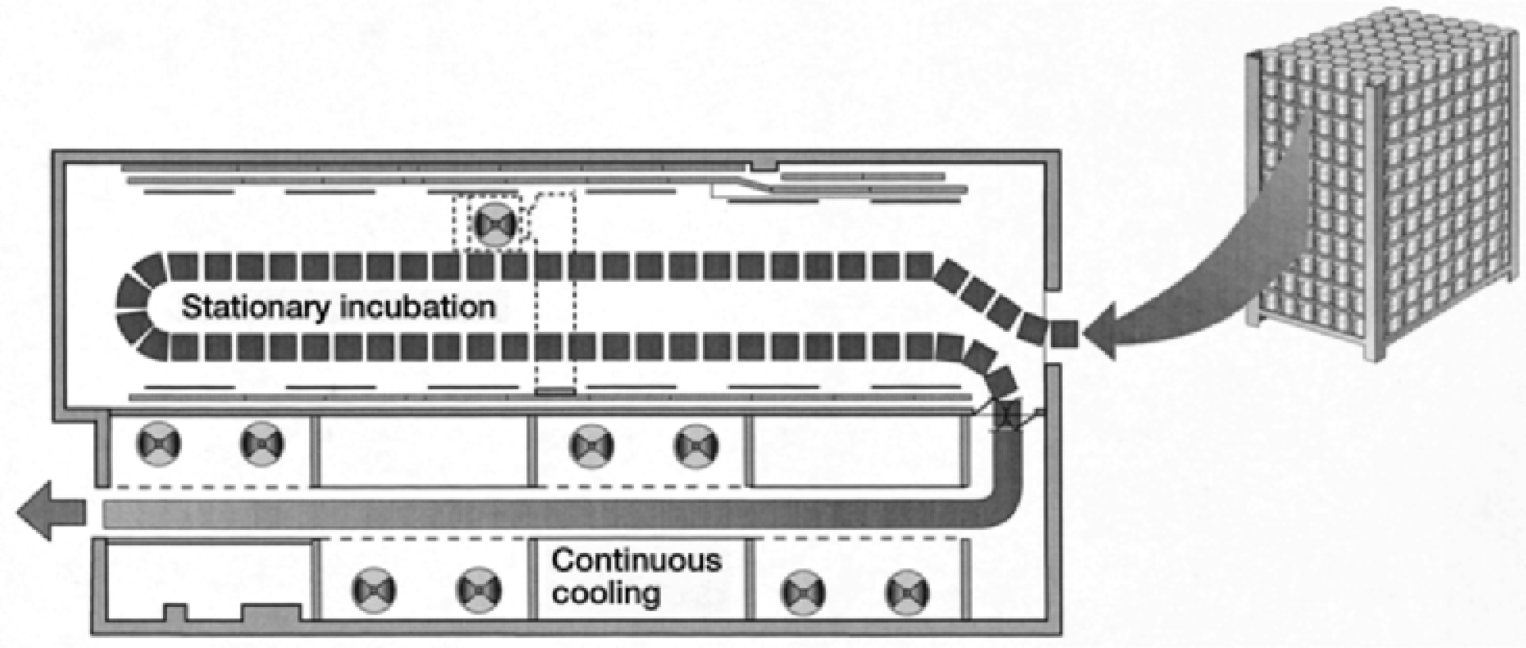

Fig. 3.35 Combined system (incubation room and cooling tunnel) for the production of set yoghurt
Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

individual package, the design and material of the packages, the depth of the crate stack, the spacing between individual packages in each crate and the design of the crates. For a depth of one metre, for example, the cross section of the stack allowing free air-flow must be not less than 25% of the total area. A smaller free cross section will require higher airflows, which also means higher energy consumption.

The pallets (crates) are stationary during incubation. They are placed in the incubation section of the tunnel in such a way as to facilitate first in/first out handling. In a typical incubation period of 3–3$\frac{1}{2}$ hours, it is very important that the product is not exposed to any mechanical disturbance during the last 2–2$\frac{1}{2}$ hours, when it is most sensitive to the risk of whey separation.

The cooling capacity should be adequate to achieve the above mentioned temperature programme. As a guide, the total cooling time is about 65–70 min for small packages (0.175–0.2 kg sizes) and about 80–90 min for large packages (0.5 kg size). Eventually, regardless of the type of incubation/cooling chamber, the set yoghurt is cooled to about 5°C in the chill store.

3.3.6.2 Equipment for the production of stirred yoghurt

By contrast, the coagulum of stirred yoghurt is produced in bulk and the gel structure is broken before or during the cooling and packaging stages. However, processing the milk base for the manufacture of stirred yoghurt is similar to that described earlier (see Fig. 3.13). An illustration of a typical plant is shown in Fig. 3.36 where the processed milk base is cooled to 40–45°C or 30°C before delivery to the fermentation tanks. The types of fermentation tank used in the industry for the production of stirred yoghurt could be classified as follows.

Multipurpose tank – This type of tank has been discussed elsewhere and is designated as a multiple duty unit, that is, (a) milk processing (heating) and fermentation, (b) same as (a) but also used for cooling the coagulum, and (c) fermentation and cooling only.

The tanks are water jacketed so that steam can be used during the heating stage and circulating cold water is used to cool the milk to 40–45°C. The temperature is maintained at 42°C during the fermentation period. Finally, chilled water is circulated to cool the coagulum.

Fermentation only tank – These tanks are only insulated in order to maintain an even temperature during the incubation period. The agitation system in such tanks is optional, since the cone-shaped base facilitates easy removal of the coagulum (see Fig. 3.37). However, agitators in a yoghurt fermentation tank may be required, especially if DVI starter cultures are used and there is need to ensure rehydration and/or proper mixing into the milk; if a bulk starter culture is used, it is metered into the processed milk and hence no agitation is required (see Fig. 3.36).

Fermentation/cooling tank – This type of tank is water jacketed and warm water at 40–45°C is circulated during the incubation period, followed by cold or chilled water for partial cooling of the coagulum (see Section 3.3.7); illustrations of these tanks and others mentioned elsewhere have been reported by Tamime and Greig (1979) and Robinson and Tamime (1993). One such example is the Goavec tank which has an increased surface area to improve the efficiency of cooling the yoghurt (Goavec, 1983).

Aseptic fermentation tank – This type of tank is a modified version of the standard fermentation unit. The tank is used for the production of yoghurt under aseptic conditions. The overall specifications are:

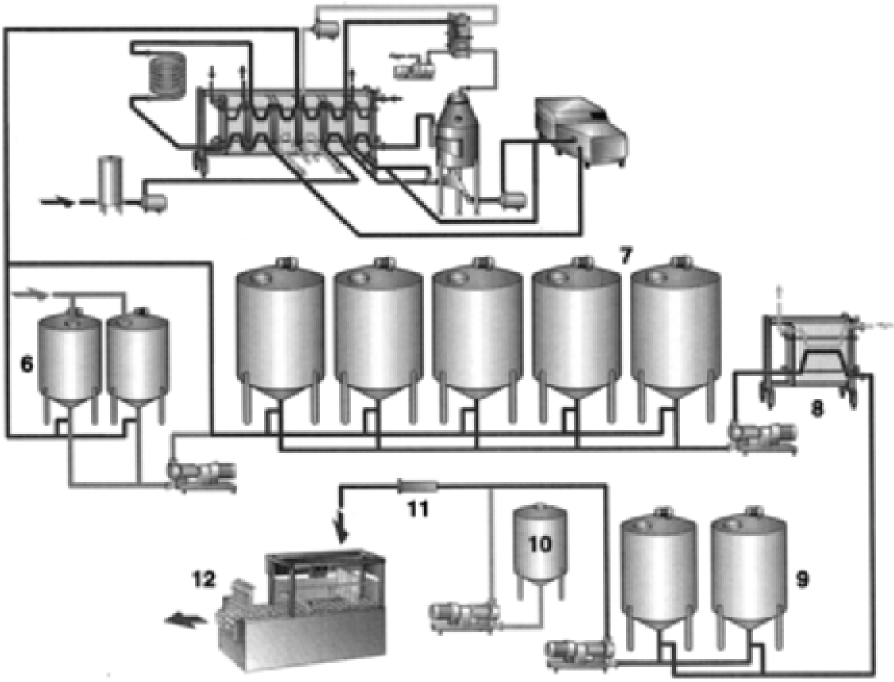

Fig. 3.36 Production line for stirred yoghurt

Details of pretreatment of the milk base are given in Fig. 3.13; 6, bulk starter tanks; 7, fermentation tanks; 8, plate cooler; 9, buffer tanks; 10, fruit flavour tank; 11, in-line yoghurt/fruit mixer; 12, filling machine.

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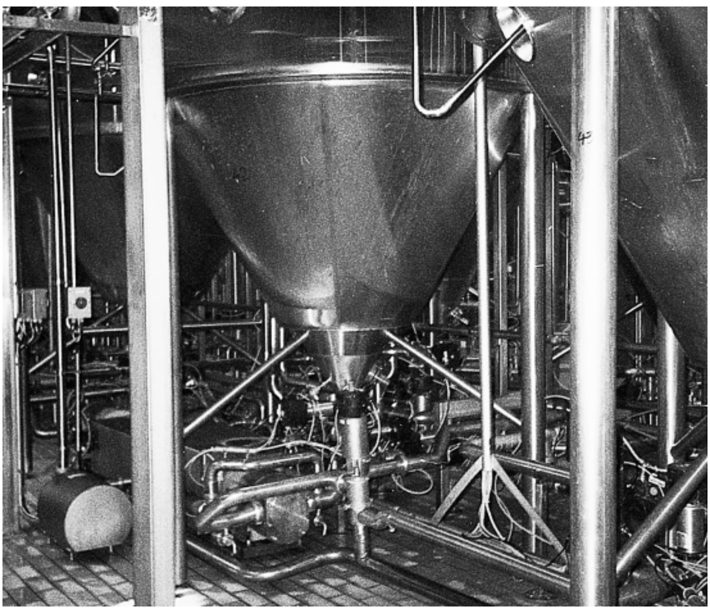


Fig. 3.37 Conical-shaped fermentation tank designed for easy discharge of yoghurt from the base

Reproduced by courtesy of Delta Dairy S.A., Athens, Greece.

- The tank is insulated.
- It is fitted with two pH electrodes and a resistance thermometer.
- The air entering or leaving the tank is filtered.
- The agitator has a double-shaft seal with steam barrier to minimise contamination.

The primary objective of using an aseptic fermentation tank is to minimise contamination of the yoghurt with yeasts and moulds. As mentioned earlier the aseptic tank is permanently pressurised under sterile air; a similar concept is used for the production of bulk starter using an aseptic tank (see Fig. 8.8 in Chapter 8). According to Bylund (1995), the air filtration system required for four fermentation tanks would consist of:

- one air fan delivering 400 m^3 $hour^{-1}$ of filtered air (about 100 m^3 $hour^{-1}$ per tank)
- one filter capable of trapping particles >0.3 μm
- one casing for the filter and one basic duct
- four connecting pipes, valves and manometers.

As a safeguard, each tank is equipped with an extra pipe for the air and a safety system to prevent the tank from imploding as a result of the vacuum created by the drop in temperature after cleaning. The air velocity is about 0.5 m s^{-1} and the tank is positively pressurised to about 5–10 m water gauge which is equivalent to 0.005–0.01 MPa (see also Müller, 1995).

It is important to note that all the tanks mentioned above have a foam-reducing inlet fitting that decreases the problem of froth formation in the tank. In addition, most modern yoghurt fermentation tanks are fitted with pH sensors to monitor lactic acid production by the starter organisms. Reviews of such developments have been published by Watanabe *et al.* (1994), Corrieu *et al.* (1994) and Mulchandani *et al.* (1995).

3.3.7 Cooling

At the desired level of acidification, cooling of the coagulum commences, so that the temperature is reduced from 40–45°C to 20°C or in some cases <10°C (Anon., 1977). The basic objective is, of course, to slow down the metabolic activity of *S. thermophilus, L. delbrueckii* subsp. *bulgaricus* and the bio starter cultures and, if the cooling process is delayed, the yoghurt or related product may become unpalatable due to the presence of too high a level of acidity. As mentioned elsewhere (see Section 2.11 in Chapter 2) the cooling of yoghurt may be carried out in stages. Therefore, depending on the type of equipment used for cooling the yoghurt and the duration of the cooling period, it is recommended that cooling should start at around 0.8–1.0 g 100 g^{-1} lactic acid, so that the acidity of the cool yoghurt will be between 1.2–1.4 g 100 g^{-1} lactic acid. The systems available for cooling the yoghurt are as follows.

3.3.7.1 Chilled air

This method of cooling is widely employed in two areas in the yoghurt industry. Chilled air is circulated in cabinets and tunnels to cool set yoghurt at the end of the fermentation period. It is also circulated in the cold store, transport vehicles and retail stores. The recommended temperature for yoghurt during storage, distribu-

tion and retailing is <10°C, otherwise the keeping quality of the product will be severely impaired.

3.3.7.2 In-tank cooling

The system by which yoghurt is cooled in the fermentation or multipurpose tank is known as in-tank cooling and chilled water is usually circulated in the jacket during the cooling period. The rate of cooling the coagulum from 40–45°C to 20°C or <10°C is governed by:

- area of the contact surface
- speed of agitation
- temperature differential between the cooling medium and the product
- mass flow rate of the cooling agent
- contact time between the product and the cooling surface.

Therefore, a fast rate of cooling can be achieved by providing: (a) as large a cooling surface as possible, (b) a rapid flow rate of the cooling agent by forced circulation, (c) a steep temperature gradient between the yoghurt (40–45°C) and the cooling agent (i.e. chilled brine at –3.8 to −4.0°C), and (d) adjustment of the contact time between product and cooling surface, that is, by continually replacing the cooled yoghurt with warm yoghurt.

These factors are, of course, interrelated, but for convenience their effect on the efficiency of in-tank yoghurt coolers can be assessed separately.

Surface area – The surface area available for cooling yoghurt may vary considerably from one tank to another. Figure 3.38 shows how this area could be maximised. The in-tank cooling rates of yoghurt can differ widely, and while, for example, the 50001 tank (Fig. 3.38, type (2)) may require 4 hours to cool the yoghurt from the incubation temperature to about 5°C, yoghurt in tank type (4) (see Fig. 3.38) requires $\frac{1}{2}$ hour to cool from 45°C to 20°C (Jay, personal communication; Hale, personal communication).

Agitation system – The different flow patterns which occur during liquid mixing are discussed elsewhere (see Fig. 3.23), and the factors that affect the performance of an in-tank yoghurt cooler are basically:

- shape of the tank
- shape of the agitator system (paddle, propeller, scrape surface or anchor)
- size and position of the agitator
- speed of rotation
- velocity difference between the bulk fluid and the agitator.

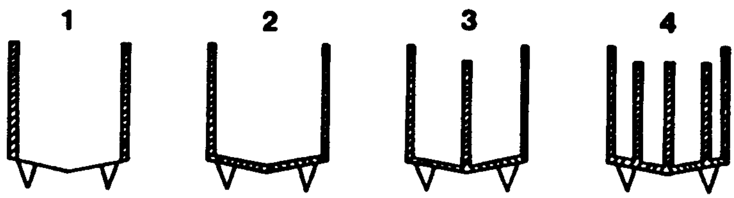


Fig. 3.38 Diagram of the surface areas of some in-tank yoghurt coolers

Shaded area is the cooled region; 1, side of tank; 2, side and bottom of tank; 3, side, bottom and inner cylinder; 4, same as in (3) plus in-tank cooling coils.

The creation of a vortex and/or incorporation of air into the bulk of the yoghurt are not desirable, and similarly, stirring of the warm coagulum may cause shearing; these effects can be minimised by controlling the speed of rotation and adjusting the shape of the agitator. The shearing effect is also influenced by the difference in velocity between the bulk yoghurt and the agitator tip, and a reduction in velocity differential will minimise the rate of shear. It is for this reason that more than one type of agitation system may be provided in a yoghurt tank. The design of the agitation system seeks, therefore, to minimise structural damage to the coagulum. Some examples of suitable systems are first, the scraped surface agitator plus, for example, a centrally mounted helical paddle, second, the contra rotating paddle, third, the scraped surface agitator only; however the 35° cone-base tank assists in turning the yoghurt gel with minimum structural damage and the scraping action of the agitator continually replaces the cool yoghurt with warm yoghurt, thus improving the rate of cooling, and fourth, a paddle agitator plus fixed baffles along the side of the tank.

Speed of rotation – The agitator speed is reduced as much as possible to give effective mixing of the coagulum but minimum shearing. Some commercially available tanks reflect this aim with the speed of rotation ranging between 8 and <50 rpm. In some instances, two-agitator systems rotating in opposite directions may be installed in a tank or one agitator paddle may be needed which can rotate clockwise or anti-clockwise alternately. Nevertheless, the in-tank cooling of yoghurt requires a long time and according to Kessler (1981), the formula used to measure the heat transfer in a tank during the heating of milk can be used to calculate the time required to cool the yoghurt. He illustrated this point with the following example:

Time of cooling (s)

$$= \frac{\text{Volume } (\text{m}^3) \times \text{Density of yoghurt } (\text{kg m}^{-3}) \times \text{Specific heat } (\text{J kg}^{-1}\,\text{K}^{-1})}{\text{Effective heat/cool exchange area } (\text{m}^3) \times \text{Heat transfer coefficient } (\text{W m}^{-2}\text{K}^{-1})} \ln \frac{\text{Temperature of warm yoghurt} - \text{Temperature of cooling medium}}{\text{Temperature of cool yoghurt} - \text{Temperature of cooling medium}}$$

$$= \frac{3 \times 1040 \times 3800}{9.55 \times 150} \qquad \ln = \frac{40 - 15}{20 - 15} = 1.61$$

$$= \frac{3 \times 1040 \times 3800}{9.55 \times 150} \times 1.61$$

$$= 13\,235 \text{ s} = 222 \text{ min} = 3.7 \text{ hours}$$

where ln is the natural logarithm. High speed agitation was used during cooling.

It is clear that chilled water rather than mains water should be used in order to maximise the temperature differential between the warm yoghurt and the cooling agent and if the surface area can be increased, the cooling time will also be reduced.

An alternative technique for the in-tank cooling of yoghurt would be the insertion of a heat exchanger (plate or coil) into the coagulum at the end of the fermentation stage (Ehrmann, 1972). However, this type of apparatus restricts the use

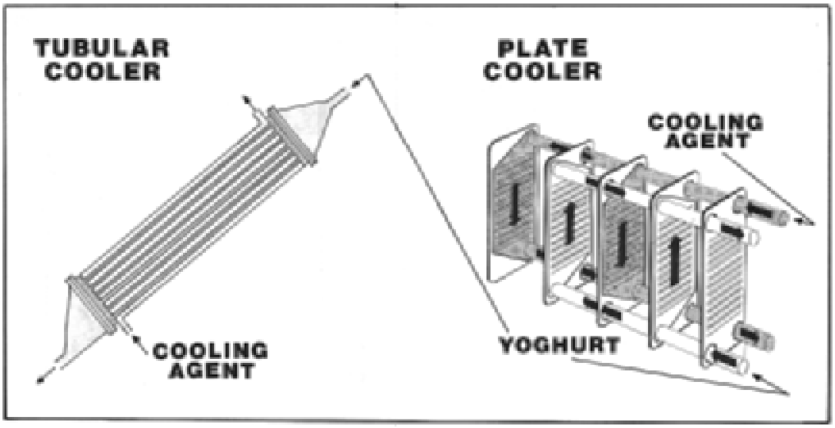


Fig. 3.39 Flow of yoghurt through different types of coolers
Notice that the streams of yoghurt and cooling agent run in counter current mode.
After Tamime and Greig (1979). Reproduced with permission of *Dairy Industries International.*

of agitators in the tank and since these coolers are inserted into the coagulum after the incubation period, problems of contamination may arise.

3.3.7.3 Continuous coolers

In contrast to the slow heat transfer of in-tank or batch coolers, more rapid cooling of yoghurt can be achieved using either plate or tubular heat exchangers. The flow pattern of yoghurt through a heat exchanger is illustrated in Fig. 3.39. It is normally accepted that the throughput/unit time of plate or tubular cooler should be roughly double the capacity of the processing plant, so that if the plant capacity ranges from 3500 to 40001 hour^{-1}, then the capacity of the cooler should be in the region of 80001hour^{-1}.

The plate cooler is similar in design to the conventional plate heat exchanger described earlier, except that the gap between the plates is much larger (e.g. up to 6mm compared with 2.5mm), so minimising the risk of structural damage to the coagulum. In addition, because of the tendency of back pressure to build up in a plate cooler, either the passage of yoghurt has to be restricted, or alternatively, the gap between the plates is increased progressively across the unit. It is further recommended that the throughput of a plant should be increased by installing a number of small units in parallel rather than by increasing the number of plates on a large unit. The cooling agent in a plate cooler is usually chilled water and an approximate water consumption of 400001 hour^{-1} can be anticipated for a plate heat exchanger cooling 80001 of yoghurt hour^{-1}.

The tubular cooler is constructed of a bundle of tubes enclosed in a shell and, as the product passes through the tubes, a counter current flow of cooling agent passes around them. Some technical specifications of this type of cooler, which is produced by Terlet/Zutphen, are: (a) sizes range from 1000 to 100001hour^{-1}, and it is recommended that capacity should be the same as the filling machine, (b) chilled water flows counter current to the yoghurt and the consumption of water is roughly five

times the product volume, (c) the time required to cool yoghurt from the incubation temperature (40–45°C) to 8°C is 1 hour and the velocity of the yoghurt through the tubes is $0.65\,cm\,s^{-1}$, (d) any reduction in viscosity is minimised by transferring the yoghurt from the tank to the cooler by providing the right plant installations (see Sections 3.3.8 to 3.3.12), and (e) plant design is simplified by the fact that these coolers can be placed in various positions (i.e. vertically or horizontally).

It is inevitable that some structural damage to the coagulum will occur during the passage of yoghurt through either plate or tubular coolers, but Steenbergen (1971a) and Piersma and Steenbergen (1973) concluded that least loss of viscosity occurred in a tubular cooler. However, purging of the product at the end of the production may be necessary to minimise yoghurt loses before the CIP stage.

3.3.8 Pumps

A variety of different pumps are used in the dairy industry, depending on their intended function. For simplicity the production line can be divided into the following sections:

- liquid milk handling and processing
- coagulum production and handling
- fruit/yoghurt blending and packaging.

The physical characteristics/consistency of the materials differs in each section and it is vital that the type of pump is suitable for its duty. This is especially true after the formation of the coagulum, since any harsh mechanical treatment can ultimately affect the viscosity of the product. Nevertheless, in large yoghurt plants the milk base is pumped through long pipelines with many valves, and through heat exchangers, filters and other equipment which may result in high pressure drops. Therefore, pumps are used in different parts of the processing plants and it is important that the right type of pump is installed at the right place in order to avoid problems. According to Castaigne *et al.* (1985) and Bylund (1995), aspects to be considered are:

- pump installation
- suction and delivery lines
- type and size of pump required should be selected with regard to flow rate, product to be pumped, viscosity, density, temperature, pressure in the system and/or material in the pump.

3.3.8.1 Centrifugal pump

Basically, this pump consists of an electric motor (to supply the energy), a rotating impeller enclosed in a casing and a delivery chamber. The fluid enters the impeller chamber and is accelerated centrifugally until it is forced outward along the tip of the impeller. As a result, the fluid is discharged into the delivery chamber and out through a port in the casing of the pump. The pressure generated is always equivalent to the flow resistance of the process line and the efficiency of the pump, that is the transmission of energy from the motor to the liquid via the impeller, is equal to:

$$\text{Efficiency of centrifugal pump} = \frac{\text{Kinetic energy} + \text{Pressure energy imparted to the liquid at discharge}}{\text{Energy delivered by the motor}}$$

Note that the energy loss in the form of heat is ignored.

All centrifugal pumps are the same in principle, but the design of the impeller can vary and certain other factors have to be considered, namely:

- discharge pressure at the pump,
- flow rate or velocity of the liquid,
- degree of cavitation (this is the result of liquid being transferred from one side of the pump to the other, thus creating a vacuum; the new liquid enters the pump by suction),
- viscosity of the product can affect pressure loss in the pump and losses are higher when viscous products are being moved due to an increase in friction,
- if pressure losses occur in the processing line, the velocity of the fluid is controlled either by installing regulating valves, or by using a speed control, or by changing the diameter of the impeller.

The centrifugal action of these pumps is capable of producing high shear forces in the liquid being pumped and hence their application in yoghurt processing is restricted to liquid milk handling and the pumping of water (hot or cold) through the heat exchangers.

3.3.8.2 Piston pump

A piston pump could be described as a piston that reciprocates in a cylinder; inlet and outlet valves control the flow of liquid so that it flows in the right direction. In general, piston pumps are used in dairies as metering pumps. However, a homogeniser could be also considered as a type of piston pump. Thus, this type of pump can be used to achieve high pressures during the processing of the milk base (see Chapter 2 and Section 3.3.4).

3.3.8.3 Positive displacement pumps

The positive displacement pumps are classified into three different groups, rotary, reciprocating and miscellaneous. The principle of a positive displacement pump is that for each revolution (i.e. rotary type pump) or each reciprocating movement, a net amount of liquid or product is pumped regardless of manometric head (H) (Bylund, 1995). However, when pumping non-viscous products (i.e. milk) some slip or internal leakage may occur as the pressure builds up, and this will reduce the flow per revolution or stroke (i.e. in the reciprocating type pump). The incidence of slip is reduced with an increase in viscosity, as is the case with yoghurt.

Throttling the outlet of a positive displacement pump will increase the pressure dramatically. Hence it is important that no valves after the pump should be closed, and that the pump should be fitted with a pressure relief valve built into the pump or as a by-pass valve. When using these types of pump, the flow is normally controlled by regulating the speed of the pump or adjusting the stroke of a reciprocating pump. When pumping high viscosity products (e.g. yoghurt), the following precautionary measures most also be considered. First, the pump should be located very close to the product feed tank and second, the pipe diameter must be large (see later). These precautions ensure that only low pressure drops occur, otherwise if the pressure drop is high, the pump will cavitate. The same conditions also apply to the outlet side of the pump where high pressure can occur if long and narrow diameter pipelines are installed.

A pump classified as a reciprocating displacer is, in effect, a low pressure piston pump and although not used for the direct movement of the yoghurt coagulum, the majority of filling machines incorporate the basic design. Thus, although this type of

pump may exert a slight shearing effect, damage to the coagulum is minimised due to the short contact time between the pump and the yoghurt, the low temperature of filling, i.e. ≤20°C and the absence of back pressure.

Lobe-type rotary pumps – These rotating displacement pumps are the most popular type for yoghurt, for the product moves through a rotating cavity between two rotors each constructed with bi-, tri- or multilobes. The design of the rotor lobes makes them suitable for pumping yoghurt containing delicate solids (e.g. large fruit pieces). The flow pattern of yoghurt through these different pumps is illustrated in Fig. 3.40. When the rotors rotate, a vacuum is created at the inlet side of the pump which draws the yoghurt into the pump. The product then flows along the periphery of the pump casing towards the outlet side of the pump; there the volume of yoghurt is reduced and the product is forced through the outlet (see Fig. 3.40). In general, each rotor is independently driven by a timing gear located at the back of the pump; however, the rotors do not touch each other or the pump casing even though the clearances between all parts in the pump are very small (Bylund, 1995).

According to Tamime and Greig (1979), the advantages of these positive displacement pumps, compared with reciprocating pumps, are:

- cheaper drive train,
- can operate at a higher speed (these pumps are cheaper and smaller than piston pumps with comparable delivery rates; however, since the speed of pumping affects the viscosity of yoghurt, the application of high speed is not recommended,
- negligible surges of flow,
- pumps are self priming,
- suitable for applications where large heads are involved,
- high delivery rates,
- suitable for pumping viscous products (e.g. yoghurt), or mixtures of solids and liquids (the suspended solids should not be sharp or abrasive),
- volumetric efficiency hardly diminishes with increasing counter pressure.

Some illustrations of bi- (SK range) and tri-lobe (SR range) positive displacement pumps are shown in Fig. 3.41. However, it could be argued that the bi-lobe pump provides smoother displacement and low shear. The top inlet of the product and

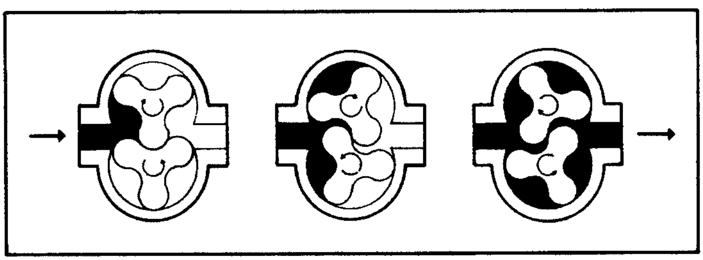
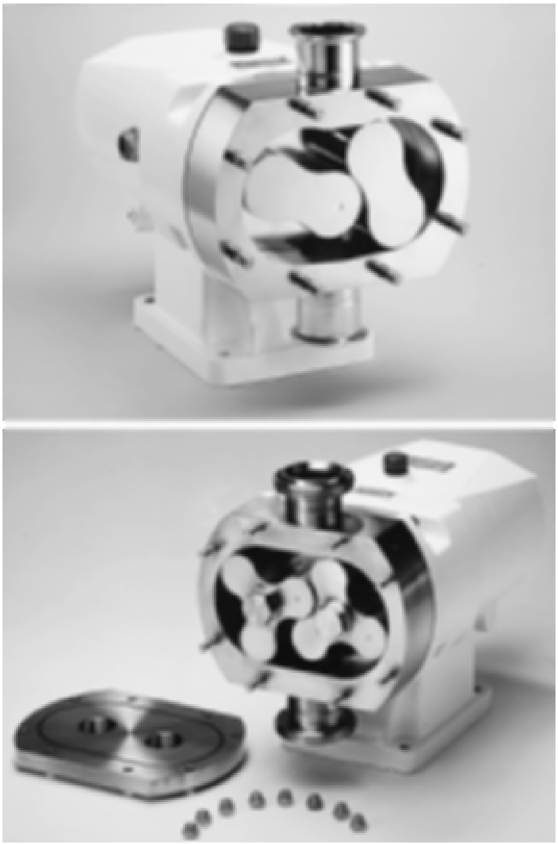


Fig. 3.40 Flow of yoghurt through a lobe rotor of a positive displacement pump
After Tamime and Greig (1979). Reprinted with permission of *Dairy Industries International*.



(A)

(B)

Fig. 3.41 Illustration of bi- (A) and tri-lobe (B) SSP rotary positive displacement pumps
Reproduced by courtesy of Alfa Laval Pumps, Eastbourne, U.K.

bottom outlet design provides full drain down between batches with virtually no product residue to cause contamination. In the past, one criticism of the rotary displacement pump was that the seals were prone to leakage and Harper *et al.* (1976) have pointed out that the seals between the pressure and suction sides are not as efficient as in reciprocating pumps. The seals between the rotary gears and the face plate are also prone to leakage. Regular inspection of the seals can reduce these problems to a minimum. However, over the years the design of these pumps has been improved to meet specific applications in the industry. For further details refer to Anon. (1984, 1985, 1989a), Verheij and Langeveld (1985) and Maynard (1991). More recently, the use of titanium (i.e. parts of machinery made from or lined with) and in particular pump components for the dairy industry has been discussed by Repenning (1995).

Wing-type rotary pumps – An alternative lobe design for the rotors of a positive displacement pump uses a single or twin-wing rotor. An example of such a pump is the Waukesha Universal Series, shown in Fig. 3.42. The single wing rotor ensures minimum breakage and better filling of fluids with discrete particles such as fruit

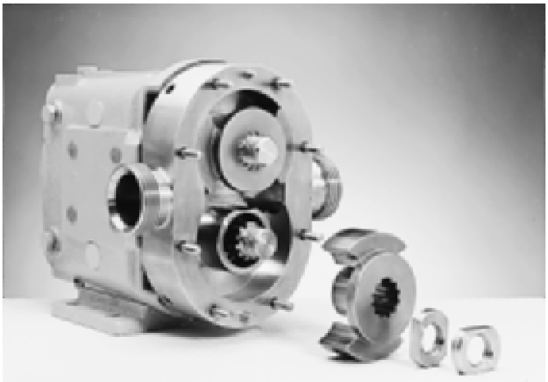


Fig. 3.42 Illustration of twin-wing rotor used in a rotary positive displacement pump
Reproduced by courtesy of Alpha Technical Services, London, U.K.

Fig. 3.43 The Mono S range screw-type rotary pump
Reproduced by courtesy of Mono Pumps Dresser, Manchester, U.K.

flavoured yoghurt, fruit preserves, pie fillings and large curd cottage cheese (see also Anon., 1985, 1989b, 1991).

Screw pump – Another type of positive displacement pump is known as the eccentric screw, helical or screw pump, widely used for pumping fruit yoghurt. It consists of a single helical rotor turning within a resilient stator. The fruit/yoghurt travels along a continuous spiral path without changing volume; in this way the yoghurt coagulum is treated gently and the fruit particles remain intact (Fig. 3.43). This type of pump must be filled with yoghurt before starting. However, the primary

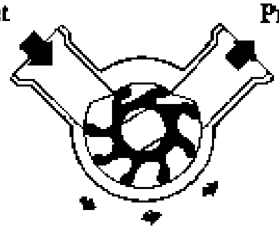


Fig. 3.44 Diagram to show the operation of a flexible impeller pump

objective of the initial filling is not for priming purposes, but to provide the necessary lubrication of the stator until the pump primes itself. Therefore, the pump should never be run in a dry condition because the stator will be damaged.

Some screw-type pumps (i.e. Mono Dresser) are provided with a "Flexishaft" that links the drive shaft to the helical rotor. In other pumps the shaft drive is reversible so that it can be driven in either direction (e.g. PCM Moineau pump).

3.3.8.4 Flexible impeller pump

This pump works on the principle that as the impeller blade leaves an offset plate it creates a vacuum, so that on start-up, air in the inlet pipe is displaced and yoghurt is drawn into the pump and then carried through to be discharged from the outlet at a steady flow rate (see Fig. 3.44). As the flexible vanes of the impeller come into contact with the offset plate again they bend and the squeezing action forces the product to be discharged continuously. The impeller can be manufactured from various types of inert material (e.g. Neoprene) which is widely employed in the dairy industry for continuous operation at temperatures up to 65°C, and up to 90°C for CIP. A typical pump of this type is made by ITT Jabsco; incidentally, the same company manufactures a wide range of pumps that can be used in the yoghurt industry (see Fig. 3.45). A rotor with a scimitar design is supplied by the same pump manufacturer.

3.3.8.5 Diaphragm pump

Air-operated diaphragm pumps are used in the yoghurt industry to transport a product including fruit pieces without any damage. A typical example is shown in Fig. 3.46 (L-series), made from highly polished stainless steel for hygienic processes. However, mechanically powered diaphragm pumps are better suited as metering pumps because, in the air-operated type, there are pulsations in the outlet pressure and the capacity will change with changing product pressures since the air pressure is kept constant (Bylund, 1995).

In principle, the air-operated diaphragm pump is a double-acting positive displacement pump with two alternating pump chambers (see Fig. 4.46). Compressed air, which is required to operate the unit, is admitted through a control valve at the rear of each diaphram in turn; this action displaces the yoghurt from the alternate pump chamber; also the diaphragm ensures that the pumped yoghurt is separated from the air. As the diaphragm retracts, a vacuum is created within the unit and the

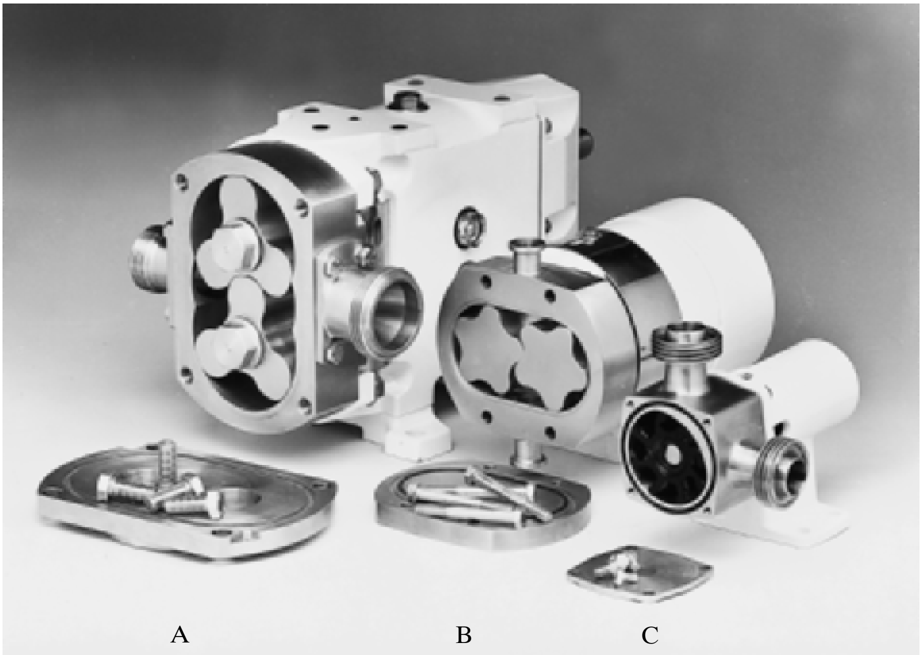


Fig. 3.45 Illustration of different types of Jabsco rotary pump

A, Tri-lobe 24 series; B, 5 lobe rotor 55 series including the scimitar lobe (design not shown); C, flexible impeller 28 series.

Reproduced by courtesy of ITT Jabsco, Hoddeson, U.K.

product flows into the chamber. At the same instance, the volume of the opposite chamber is reduced and the yoghurt is discharged through the upper ball valve (see Fig. 4.46). A common piston rod (see large arrows in Fig. 3.46) connects the two diaphragms together. Since the pressure is the same (i.e. compressed air section and pumping chambers) during each stroke, the actual diaphrams are not subjected to a large pressure differential and hence last for long operational periods.

3.3.8.6 Peristaltic pump

This type of pump consists of three parts, a flexible plastic pipe, a curved track which houses the plastic pipe and a motor that drives a series of rollers which, in turn, occlude the tube and thus push the fluid along. The action of the roller also creates a powerful suction or vacuum in the tube and, as a result, fluid is drawn in to replace that being driven forward; the flow rate is governed by the speed of the roller and the internal diameter of the flexible plastic pipe. According to Bylund (1995) the volume between the rollers is equal to half the volume conveyed per rotation. Therefore, the product is pumped to the outlet connection during rotation and, at the same time, the same amount is drawn in on the suction side of the pump.

Incidentally, this type of pump is also referred to as a hose pump, and although it can be used for transportation of the product, in the yoghurt industry it is used for accurate in-line metering of colouring matter and/or liquid (flavour) essences into the processed milk during the production of set-type flavoured yoghurt and/or

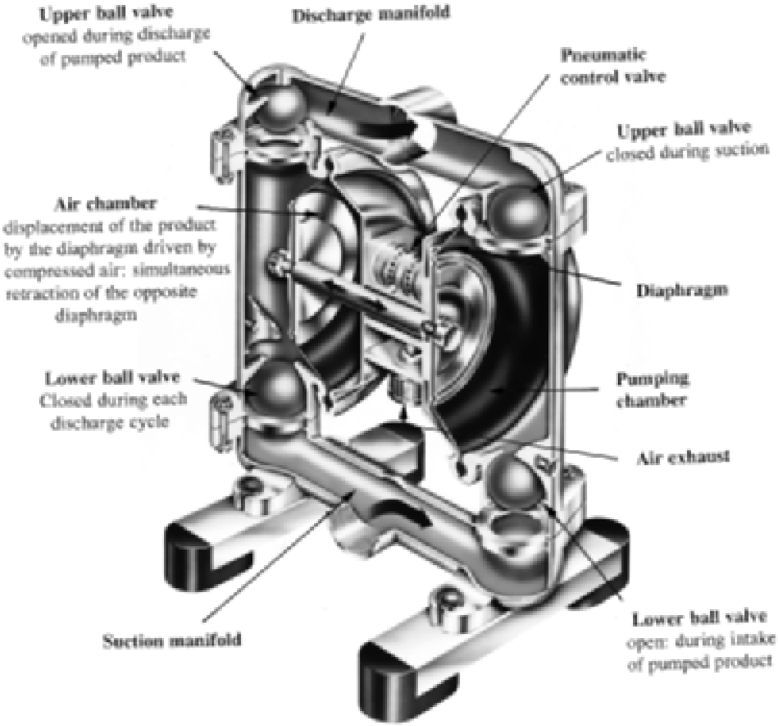


Fig. 3.46 DEPP air operated diaphram pump – series L
Reproduced by courtesy of Alfa Laval Pumps, Eastbourne, U.K.

drinking yoghurt. As this type of pump is self priming, it is suitable for emptying containers as well.

Different types of pump are used in the yoghurt processing line and in choosing the right pump for the right job, a number of interrelated factors must be taken into account. Some practical considerations may include:

- Length and diameter of the piping used on the suction and the discharge sides of the pump.
- Number and types of fitting installed, i.e. elbows, T-pieces and types of valve
- Types of metering/mixing device used.
- Manufacturer's specifications provided on the plate/tubular coolers intended for cooling the coagulum.
- Restrictions in the processing line, e.g. static in-line mixers, strainers or structurisers (see later).
- Product variables, which may include: (a) level of solids in the milk/yoghurt, (b) effect of shear on the product, (c) final viscosity of the yoghurt, (d) ability of the product to withstand high pressure pumping, (e) product type, e.g. level of pH, presence of particulate solids (fruit pieces), and (f) type of fluid flow in the system, e.g. laminar flow for yoghurt, $R < 2000$.
- Total pressure losses in the system.

Few data are available regarding the damage that may result from pumping the yoghurt coagulum from one point to another, but the classical study by

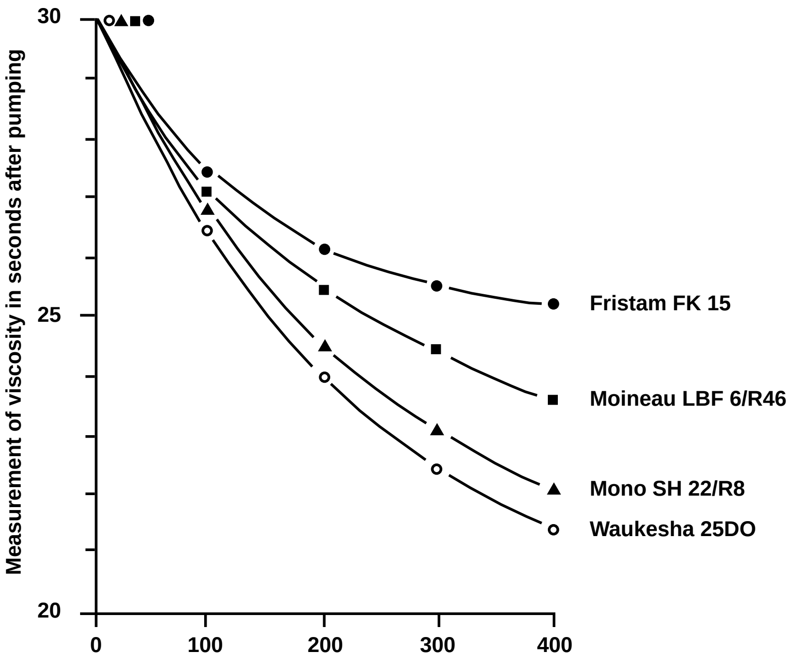


Fig. 3.47 Effect of pumping on the viscosity of yoghurt

Note that viscosity measurement was carried out using the Posthumus funnel (see Galesloot, 1958) and counter or back pressure was 0 MPa.

Adapted from Steenbergen (1971b).

Steenbergen (1971b) has shown the effect of pumping on the viscosity of yoghurt (see Fig. 3.47) and it was concluded that the important aspects were:

- speed of the pump
- shape and type of the impeller
- counter pressure in the processing line.

Figure 3.47 shows that minimal reductions in viscosity occurred when the speed of the pump was maintained at 100 rpm; the loss in viscosity varied from 8.3 to 11.7% depending on the type of pump used. However, as the speed of the pump was gradually increased from 100 to 400 rpm, structural damage to the coagulum did occur so that if an increase in throughput is required, it is advisable to choose a pump with a larger stroke volume, rather than to increase the speed of the pump.

The development of counter pressure in any type of yoghurt plant is the result of a multitude of factors, for example, the type and number of fittings, arrangement of pipework and/or heat exchangers, and the greater the counter pressure in the system, the lower the viscosity of the yoghurt after pumping. Table 3.3 illustrates this effect. However, a high fluid flow is desirable in the plant during the CIP stage and hence the pumps used between the fermentation tanks and the filling machines must be of variable speed.

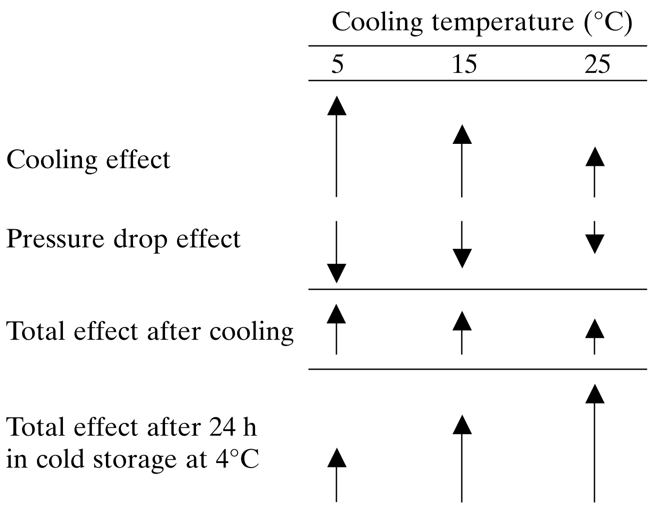
According to Nilsson and Hallström (1990), the correct selection and design of the plate or tubular coolers is essential in order to maintain optimal product quality.

Table 3.3 Reduction in the viscosity of yoghurt as affected by counter/back pressure

Pressure (MPa)	Pump speed (rpm)	Viscosity		
		Initial (s)	Observed (s)	Reduction (%)
0.0	100	60	51.0	15.0
0.1	100	60	47.5	20.8
0.2	100	60	45.0	25.0

Type of pump – Waukesha 25 DO. Viscosity measurement by Posthumus funnel (see Galesloot, 1958). Adapted from Steenbergen (1971b).

These cooling units should be designed for low product velocity, as this results in a low shear force and low pressure drop; these effects could also minimise the mechanical damage caused by the pump as the total pressure in the system is then lower. For example, the use of ice-water as a cooling agent is not recommended because too low a product temperature may be reached locally and, thus, increase viscosity and ultimately lower or even block the flow. For this reason the yoghurt is partially cooled, mixed with the fruit and finally packaged. Therefore, the cooling temperature will influence the final viscosity of the product as follows:



Whatever precautions are taken, however, mechanical handling of the coagulum does ultimately reduce its viscosity and some recommended precautionary measures include:

- Fortification of the yoghurt milk to a higher total solids content
- Addition of stabilisers (this may be prohibited in some countries)
- Use of an exopolysaccharide (EPS) starter culture
- Agitation of the coagulum should be avoided in the fermentation tank
- Partially cool yoghurt before fruit mixing and packaging

Table 3.4 Effect of transport through pipes on yoghurt viscosity

Length of pipe (m)	Yoghurt I (initial viscosity) 30 s			Yoghurt II (initial viscosity) 40 s		
	10	20	30	10	20	30
	Reduction in viscosity (s)					
Diameter of pipe (cm)						
3.81	10	14	17	17	22	24
5.08	6	9	12	11	16	20
6.35	3	5	8	6	10	14
7.62	1	4	6	2	8	11

The flow rate is 3600 l $hour^{-1}$. Viscosity measurement by Posthumus funnel (see Galesloot, 1958).
After Steenbergen (1971c).

3.3.9 Miscellaneous fittings

Different items of equipment in a yoghurt processing line are linked together by a series of pipes, fittings (elbows, T-pieces, pipe couplings, etc.), valves, and sometimes strainers, and the passage of the yoghurt through these miscellaneous parts of the plant can cause some structural damage to the coagulum. The ways in which this damage may arise are given in the following.

3.3.9.1 Pipes

As the yoghurt is pumped at a low velocity, it is safe to assume that the flow pattern through the pipes is laminar. However, other factors can affect this flow pattern, namely:

- length and diameter of the pipe
- internal roughness of the pipe surface
- fluctuations in fluid velocity

Steenbergen (1971b, c) studied the effect of pipe length and diameter on the viscosity of yoghurt and some of his results are shown in Table 3.4. From these data it can be concluded that: (a) if the velocity and diameter of pipe are kept constant, reduction in the viscosity of yoghurt is proportional to the length of the pipe, and (b) if the velocity and length of pipe are kept constant, the larger the diameter of the pipe, the least structural damage occurs to the coagulum.

It is recommended, therefore, that large diameter pipes should be installed between the fermentation tanks and the filling machines, and that at the same time, the connections should be as short as possible.

3.3.9.2 Fittings

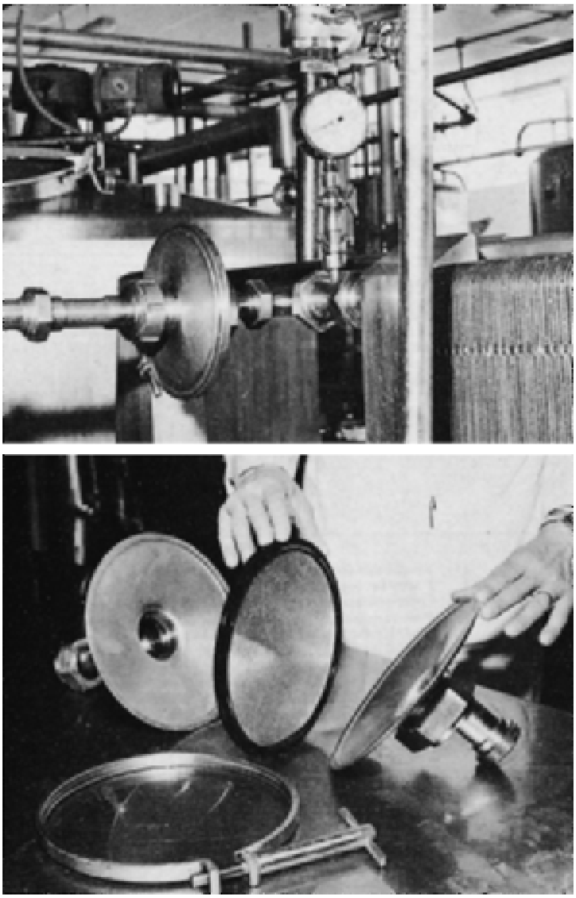
Fittings, valves and other restrictions in a processing line can interfere with the flow pattern of the yoghurt and, as a result, affect the viscosity of the product. Steenbergen (1971c, 1973) evaluated the effect of these different fittings and observed that the viscosity of yoghurt was reduced by between 0.2 s and 20 s (the initial viscosity of the product was 30 s as measured by the Posthumus funnel), which is equivalent to lowering the consistency of the yoghurt by 0.7% and 67%, respec-

tively. The most severe structural damage to the coagulum took place where fittings reduced the diameter of the piping, and if such fittings were avoided, the reduction in viscosity was minimised.

3.3.9.3 Screens, strainers or structurisers

One fault which sometimes occurs during the manufacture of stirred yoghurt is the appearance of non-dispersible particles referred to as nodules, lumpiness, granules or graininess. The nature and/or origin(s) of nodule formation is not well established (see Robinson, 1981). Although the fault can be avoided by fermenting the milk at precisely 42°C (short set) and not disturbing the gel during the coagulation period, an alternative approach is to disperse the nodules by pumping the coagulum through a stainless steel mesh. This restriction in the pipe line does affect the viscosity of yoghurt, but the advantage is that it produces a smooth textured coagulum free from nodules, a feature confirmed by Nielsen (1972); unfortunately no figure was given in relation to loss in viscosity.

One such unit, sometimes known as a structuriser, is shown in Fig. 3.48. In commercial practice, the warm coagulum is pumped through the strainer in order to



(A)

(B)

Fig. 3.48 On-site illustration (A) of a Tetra Pak 'structuriser' on a yoghurt processing plant and an exploded view of a dismantled unit (B)

Fig. 3.49 General view of Ytron®-Z "Yoghurt – Stretching" unit on a yoghurt processing plant

Note: The insert (bottom right hand) shows the labyrinth design of the rotor-stator.

Reproduced by courtesy of YTRON Process Technology, Bernau am Chiemsee, Germany.

break up the nodules. According to Fergusson (1985) the yoghurt coagulum is pumped through a filter to retain particles >1 mm in diameter and then passes through a perforated plate (strainer) followed by cooling to 5–10°C in a PHE ready for packaging. A similar type of perforated structure or sieve has been reported by Driessen *et al.* (1989); however, pumping cold yoghurt through such a strainer would severely damage the viscosity of the product, since high pressures would be required to achieve the necessary flow.

3.3.9.4 Ytron®-Z machine

This machine (see Fig. 3.49) has been developed in Germany. In it the yoghurt coagulum is subjected to an extremely short and intensive burst of shearing to smooth the product. The viscosity of the yoghurt is improved due to the mechanical action of the Ytron®-Z which causes stretching of the protein molecules. Thus, the expression "Yoghurt–Stretching"™ is associated with Ytron®, and such an effect has the following advantages:

- Gel stability is improved and the consistency of the product resembles cottage cheese or quark.
- Complete elimination of syneresis and grit or nodule formation and the product is smooth.
- The protein content in the milk base can be reduced by $0.2\,g\,100\,g^{-1}$.

The "Yoghurt-Stretching"™ effect is achieved in the rotor-stator-reactor which is constructed from toothed cages increasing progressively in slot width (see the insert in Fig. 3.49). Hence, the speed of the rotor, the slot widths in the rotor-stator set and the number of Ytron®-Z units installed ensure optimum results. The path of the yoghurt through the rotor-stator labyrinth ensures a consistent effect on the rheological properties of the product (see also Anon., 1995, 1996f).

3.3.9.5 On-line viscometer

Continuous viscosity measurements during the manufacture of fermented milks could be used to monitor the rheological properties of the product. A vibrating rod sensor has been developed by Picque and Corrieu (1988) to determine the changes in viscosity in a bioreactor during xanthan gum and fermented milk production. The sensor signals decreased non-linearly as the viscosity of the product(s) increased; if such units were to be installed on-line at different points in a yoghurt plant it would record the rheological changes in the product during pumping and/or other operations possibly contributing towards reducing the viscosity of the yoghurt. No published data are available.

3.3.10 Fruit handling and mixing units

The cool (e.g. at 20°C) or cold (e.g. at 10°C) yoghurt is delivered to an intermediate storage tank prior to further processing, that is, fruit mixing followed by packaging. The yoghurt will be retained in this tank for a short period of time or, alternatively, stored overnight, and the primary purposes of these tanks are as follows:

- The tanks are insulated and hence the temperature of yoghurt can be maintained at any desired level.
- In the event of breakdown in another section of the yoghurt factory, the tanks can act as buffer vessels.
- Overnight storage of yoghurt in the intermediate tanks can provide sufficient reserves for packaging to start first thing in the morning, rather than the machines remaining idle until the freshly produced yoghurt is available.

In this section of the processing line, equipment is required for handling the fruit, and mixing the fruit with the yoghurt. Some appropriate units are as follows.

3.3.10.1 Equipment for fruit handling

As mentioned elsewhere (see Chapter 2), the processed fruit used in the yoghurt industry is usually packaged either in metal cans, polypropylene containers (drums or buckets), flexible pouches or stainless steel tanks.

The packaging of fruit in metal cans is very popular and these cans are widely used by small- and medium-scale yoghurt manufacturers. However, large-scale producers only obtain fruit in metal cans if the demand is low and the popular flavours are either processed in the dairy or obtained in bulk in stainless steel tanks. If metal

Fig. 3.50 View of opener for metal cans
Reproduced by courtesy of D.C. Norris & Company (Engineering) Ltd., Sandy, U.K.

cans are used, a number of different types of can opener can be used, that is, hand-operated (see Fig. 3.50), semi-automatic or fully automated. The hand-operated openers employ either an electric motor or compressed air to cut the metal and remove the lid. However, the can opener shown in Fig. 3.50 is model 150 which is pneumatically operated and features stainless steel construction for all parts, has a dual safety circuit for two-handed operation, an opener that removes the metal lid in 2s, a fully enclosed knife for safety operation, and removal of the whole lid without metal chips, together with ease of cleaning.

A semi-automated can opening line can be built around, for example, model 150 (see Fig. 3.50) and the equipment might include:

- loading tables
- gravity roller in-feed section
- can washer and air blow drier
- can opener stand
- discharge section with or without product drain tray
- can product rinse
- product discharge pump
- mobile dolleys for product, empty cans and lids
- magnetic traps.

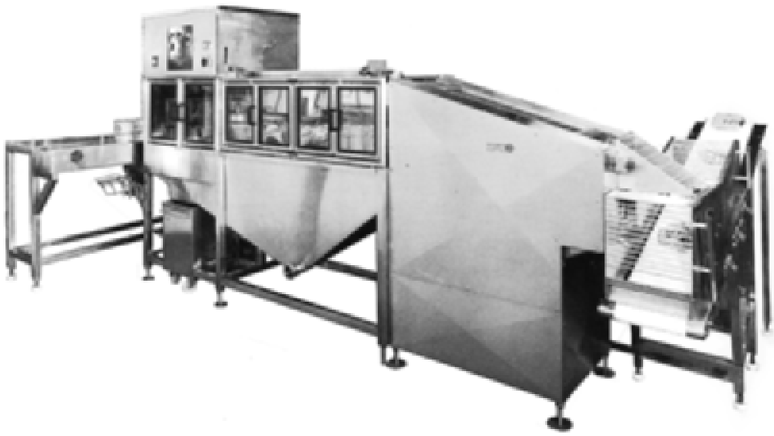


Fig. 3.51 View of an automatic can opening system
Reproduced by courtesy of D.C. Norris & Company (Engineering) Ltd., Sandy, U.K.

A semi-automatic type opener can give a throughput of 1000 cans hour^{-1}, whilst the fully automated design has a throughput up to 2500 cans hour^{-1} (see Fig. 3.51). The fully automated model has all the features listed above including automatic inversion and emptying of cans, metered water jet to clean inside the can after emptying the fruit, automatic crushing of cans, a unit constructed from heavy duty stainless steel which can be fully hoseproof for easy cleaning, and facility for CIP.

Fruits in plastic containers have to be handled manually, but if the ingredients are received in stainless steel tanks, the normal approach is to meter them directly into the yoghurt immediately prior to packaging. However, in some yoghurt processing lines the fruit is emptied onto an inclined stainless steel table and the fruit is inspected for any residual plant matter (i.e. stems and/or leaves) before mixing it with the yoghurt. As a further precautionary measure, the fruit may also be subjected to screening by metal detectors. If such a system is used, care should be exercised to minimise contamination of fruit prior to mixing it with the yoghurt.

3.3.10.2 Equipment for fruit/yoghurt blending

In large yoghurt plants, the fruit is blended with the product using either batch or continuous blending methods. However, manual blending may be used when producing fruit flavoured yoghurts of limited consumer demand (Robinson and Tamime, 1993). Examples of the equipment for fruit/yoghurt blending are:

Manual blending – This method of fruit/yoghurt mixing is illustrated in Fig. 3.7. Two tanks are used in parallel. In each tank, the required amount of fruit is added to a given volume of yoghurt, mixed gently with a plunger, and the finished blend is pumped to the packaging machines. While the first tank is being emptied, the second one is being prepared, so that the process can, in practice, become continuous.

Batch blending – In principle, the approach is similar to that described for manual blending, except that the volume of the mix is larger and hence the fruit and yoghurt are metered into a tank, mixed and then pumped to the packaging machine. Again

the process becomes, in effect, continuous through the installation of two tanks in parallel.

Continuous blending – A continuous fruit/yoghurt mixer consists of three different units: first, a metering device for dosing the correct amount of fruit into the yoghurt line, second, a metering device for measuring the required volume of yoghurt and third, a mixing chamber that ensures uniform distribution of the fruit into the yoghurt. Different types of continuous mixer are available on the market (see also Unterholzner and Maurer, 1987; Pröepper, 1988). The primary requirements are:

- Proper mixing of the fruit and yoghurt
- Minimum structural damage to the coagulum
- The fruit metering unit must be accurate to allow different fruits to be mixed with the yoghurt in the desired proportions
- Eary to dismantle for cleaning, or suitable for CIP
- All contact surfaces to be of good quality stainless steel.

Some continuous fruit/yoghurt blenders that meet these requirements are as follows.

Static-in-line mixer – Many dairy fabrication companies supply the industry with different designs for this type of mixer. A typical example is shown in Fig. 3.52, consisting of a stainless steel pipe into which a number of helical blades are welded. In practice, the static mixer is, if possible, built into the product pipeline (see Fig. 3.36 (11)) where the fruit is metered from the tank into the yoghurt stream. The flow of yoghurt/fruit through the twisted blades in the mixer ensures uniform distribution of the fruit throughout the coagulum. The specifications of such mixers are: (a) flow rates up to 10000 l $hour^{-1}$, (b) pipe diameter up to 6.35 cm, (c) lengths of the mixer ranges from 75 to 115 cm, and (d) number of blades is up to 10. Although such units can be cleaned using a CIP system, it is usually recommended that the mixers should be dismantled and rinsed before starting the CIP programme.

A portable fruit feed unit (Clarendon) fitted with a static-in-line mixer is shown in Fig. 3.53. Such a unit can operate up to 250 l $hour^{-1}$ and a flexible impeller-type pump accurately meters the fruit into the yoghurt. In order to obtain a fine adjustment of the volume of metered fruit, a trimming device can be installed within the control cabinet and the output flow is then easily controlled by means of a knurled knob located on the front of the control cabinet. An optional attachment is a six nozzle ripple head (as is used in the ice-cream industry) which can provide an effective method of incorporating both fruits and flavour into the yoghurt.

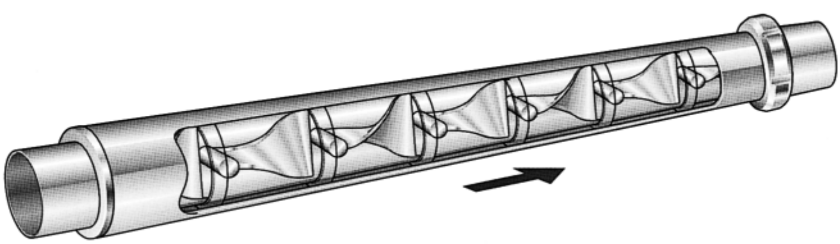


Fig. 3.52 Example of a static-in-line fruit/yoghurt mixer built into the pipeline
Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

Fig. 3.53 View of the Clarendon fruit feeder/ripple pump with a static-in-line mixer
Reproduced by courtesy of Clarendon Food & Dairy Equipment, Leaming Spa, U.K.

The dimensions of this compact unit are 75 × 35 × 100 cm high. However, for larger installations, the AutoBlend®, which is supplied by Bran Luebbe, accurately meters the fruit and yoghurt continuously and the two are blended uniformly via a static-in-line mixer.

As mentioned elsewhere (see Section 3.3.8), screw-type pumps, for example the Allweiler, are widely used for metering purposes. Fig. 3.54 illustrates the pumping of a fruit preparation from a tank into a yoghurt production line (see also Bedwell, 1984).

Gasti DOGAmix 60 – This unit (Benz & Hilgers GmbH, Germany) consists of two feeding pumps that draw yoghurt base and fruit into a mixing chamber (see Fig. 3.55). The maximum discharge rate of the yoghurt pump is 60 l min^{-1}, whilst the discharge rate of the fruit pump can be adjusted to provide the desired mixing ratio in a range between 1:5 and 1:20; however, the accuracy of metering is ± 0.5%. Both yoghurt base and fruit are discharged through a common pipe to the mixing chamber which is fitted with a dynamic agitator. The product mix is homogeneous and uniform and is fed straight to the hopper of the filling machine. The feed rate of the yoghurt/fruit mix, up to 0.3 MPa back pressure, is 75 l min^{-1}. Bacterial contamination of either the yoghurt base or the fruit during the mixing stages is avoided by isolating the moving parts of the DOGAmix (i.e. the rods of the plunger pumps and the mixer drive of the dynamic agitator) from the surrounding atmosphere by sterile air chambers. The dimensions of the Gasti DOGAmix 60 are 100 × 115 × 110 cm in height.

Fig. 3.54 Illustration showing the use of screw type pump to meter fruit from a tank into the yoghurt line

Reproduced by courtesy of Allweiller Pumps, Poole, U.K.

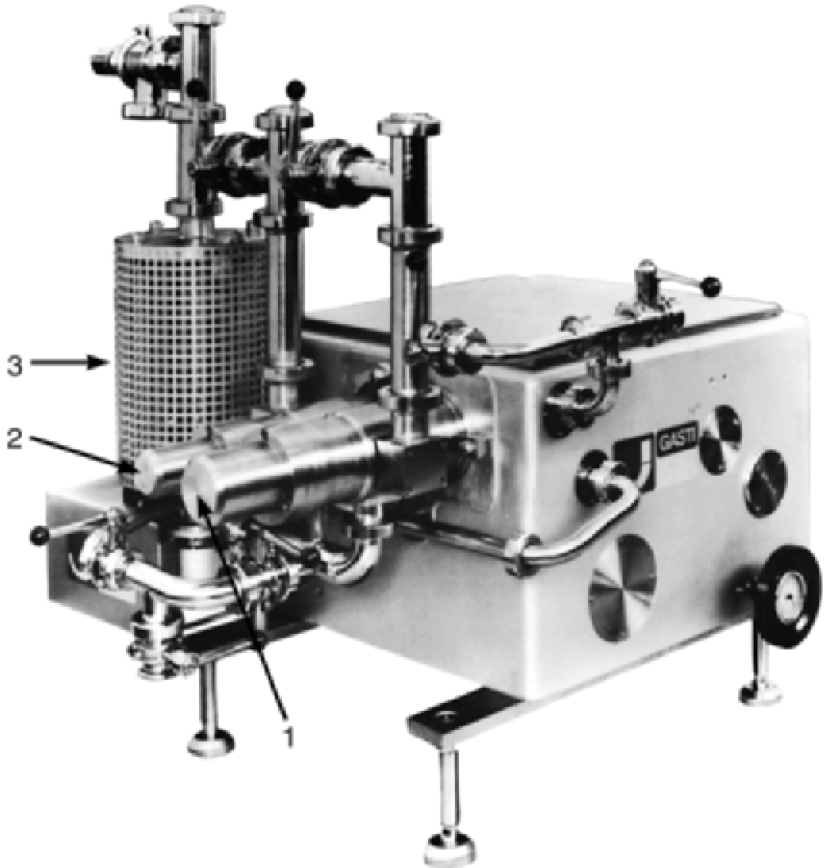


Fig. 3.55 Front view of the Gasti DOGAmix 60

1, Pump for yoghurt; 2, pump for fruit; 3, mixing tank with dynamic agitator.

Reproduced by courtesy of Jagenberg (London) Ltd., Purley, U.K.

The unit is capable of being cleaned by CIP (e.g. 1–2 g 100 ml^{-1} caustic at 80°C or 1–2 ml 100 ml^{-1} nitric acid at 80°C) and sterilised using steam at 140°C; this latter facility can be advantageous to ensure that yeasts do not build up at any point. However, the sterilisation of the air is achieved as follows:

- Compressed air passes through a filter with a water trap and automatic condensate draining, and then through a pressure regulating valve.
- Air then passes through a second high performance filter consisting of: (a) a layer of boron silicate micro-glass fibre weave, and (b) an activated carbon filter for the exclusion of oil vapour and odours.
- Finally, the air passes through sterile filter as in (a) above of 0.1–1 μm thickness; this filter is sterilised by steam (0.3 MPa pressure) at up to 140°C.

Burtech dynamic loop mixer – This in-line mixer is manufactured by Burtech Burgent Technology GmbH in Germany, also known as Burdosa Technology. Basically, the Burtech dynamic loop mixer (e.g. Supramix SLR or Unimix SLM) has a wide application in the dairy and food industries. The Supramix SLR is designed for mixing applications where high shear forces are used, whilst the Unimix SLM is designed where effective but low shear forces are required to protect the product against damage during the mixing stage.

The cross section of the Burtech dynamic loop mixer is shown in Fig. 3.56. The working principles are:

- Continuous product flow, which is made up of different ingredients that are metered into the inlet side of the mixer, is directed through the mixing chamber where, for example, yoghurt and fruit particles are constantly circulated.
- Recirculation is achieved by a central mixing tube (see Fig. 3.56) in which a rotating helical displacer supplies the energy required for particle mixing.

Other features of this type of mixer are: (a) the unit is totally closed and of hygienic design, (b) high throughput, but with small volume mixing chamber, (c) the mixer can be cleaned using CIP without dismantling, (d) trouble-free during start/stop operation, (e) low energy input and space saving design, and (f) the mixer has a flushed mechanical seal.

3.3.11 Filling machines

The fundamentals and principles of packaging, including the different types of packaging materials used in the yoghurt industry, have been given in detail in Chapter 2. However, some other relevant aspects of yoghurt packaging are: (a) the use of controlled and/or modified atmosphere packaging processes to improve the shelf life of yoghurt, cheese and other dairy products (Honer, 1988), (b) the advantages of tamper evident packaging include increased consumer acceptability, reduced product leakage and spoilage during storage, distribution and retailing (Herner, 1987; Hotchkiss, 1987), (c) the use of a sterile air chamber where the yoghurt cups can be filled (Anon., 1990a) or the sterilisation of the packaging containers using steam or hot air (Reinecke, 1985; Turtschan, 1986; Savaria, 1986; Doty, 1986; Maurel, 1996), (d) the use of a Serac R20T2OE/72A rotary-type filler equipped with 24 nozzles for aseptically packaging UHT drinking yoghurt in high density polyethylene bottles; the filling capacity is 8000 × 1 l or 11 000 × 0.5 l bottles hour^{-1} (Anon., 1989b) and (e) the development of sensors for inspection of the outer containers of

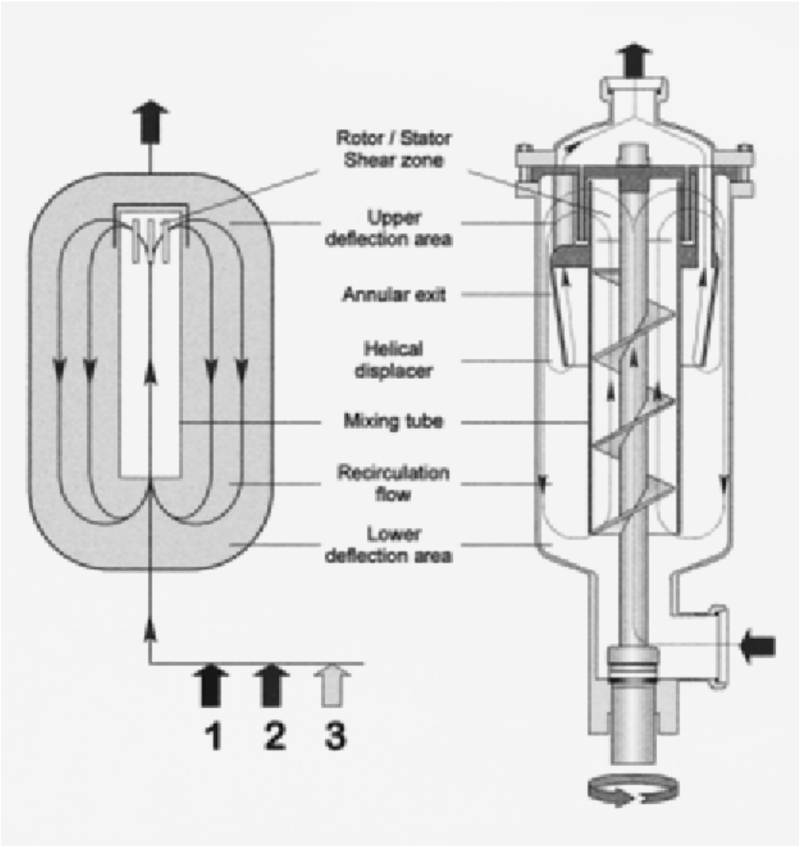


Fig. 3.56 Cross section of the Burtech dynamic in-line loop mixer
Reproduced by courtesy of Burdosa Technology, Wembley, U.K.

yoghurt for detecting, for example, defects in the quality of printing by the ink jet printer (Tomita and Shibata, 1994). Currently, there is interest in the yoghurt industry in the use of biodegradable "Eco cups" that are fully compostable in two months (Stratton, 1998); the thermoplastic container is made from polyactic acid which is derived from maize or beetroot. There is also a tendency within the industry to replace the aluminium foil laminates used to seal the plastic cups with plastic material so that metal detection in the filled cups becomes easy.

A multitude of high speed yoghurt filling machines are available on the market and although capital cost could be one of the major factors in choosing a certain piece of equipment, from a technical point of view, certain important specifications must not be overlooked. For example:

- Proposed method of filling and sealing,
- Type of unit container being used,
- Desirability of filling under a controlled atmosphere,
- Degree of automation being sought,
- Need for a high standard of hygiene (e.g. all contact surfaces must be stainless steel and accessible for sterilisation/sanitisation),

- Time required to change from one flavour to another or from one volume of carton to another,
- Versatility and reliability of the machine,
- Accuracy of filling and the elimination of drip between individual fills,
- Power and labour requirements of the machine,
- Other specifications such as availability of date marking, method of dispensing the cups, and safety measures (e.g. no cup no fill).

It would be impractical to discuss all the different types of yoghurt filling machines in detail, but it is safe to assume that the use of the positive displacement or piston pump is almost universal and that the measures are volumetric. In addition, most filling machines are equipped with marking attachments (e.g. best before date) and/or label application units (e.g. for large containers with snap-on lids). Some examples of these yoghurt filling machines follow.

3.3.11.1 Machines for filling yoghurt into preformed plastic containers

DOGAtherm 81 CIP – There are two versions of this machine which is manufactured by Benz & Hilgers GmbH in Germany. The common specifications of these models are: (a) automatic cup loader, (b) two lane filling conveyor with eight filling heads, (c) closure of the cups by heat sealing, (d) maximum output from 10000 to 15000 cups hour^{-1}, and (e) machine cleaning using a CIP system.

The DOGAtherm 81 CIP is fitted with a clean air cabinet over the machine so that filling takes place in a controlled atmosphere and the shelf life of the product is extended. Also, UV irradiation is used to sterilise the plastic cups and lids and the main dosing unit (i.e. two filling heads) has an option for two product filling. However, before placing the aluminium foil lid on the filled cup for heat sealing, the lid is stamped; provision can be made for two stamping zones (see Anon., 1990b).

For smaller operations the FLEXOtherm model can be used and both machines could be fitted with a prefiller for double layer cup filling or twin-chamber filling. A reusable plastic snap-on lid can also be applied.

Remy 54 volumeter – This machine is capable of packaging yoghurt into 500g plastic containers with heat-sealed foil covers. The plastic cups are dispensed from an enclosed magazine holder and the filling and sealing stations can be in a sterile, laminar air flow cabinet that reduces contamination of the yoghurt. The capacity of this machine, depending on the number of lanes, ranges from 8400 to 16800 containers hour^{-1}; the packaging machine is also fitted with an automatic tray packer.

COMBIseptic CS 41, 61 & 81 – These conveyor filling machines (Benz & Hilgers GmbH, Germany) are enclosed in a chamber with sterile air overpressure and have sealed, insulating doors to protect against H_2O_2 vapour emissions or noise (see Fig. 3.57). The complete line consists of a cup feeder, tray erector, integrated or separate tray packer, palletiser and separate foil lid press. Sterilisation of the packaging material is with H_2O_2 and/or UV irradiation lamps. For the latter systems, quartz screens are provided for maximum product/operator protection; this section is also air cooled and is fitted with safety guards.

The outputs of the COMBIseptic models are 9000, 12000 and 15000 cup hour^{-1}, respectively. The CONTItherm models are supplied by the same manufacturer and have ultraclean facilities as in the COMBIseptic, but the production output is 12000–19200 cups hour^{-1} (model 82) and 15000–25000 cups hour^{-1} (model 123).

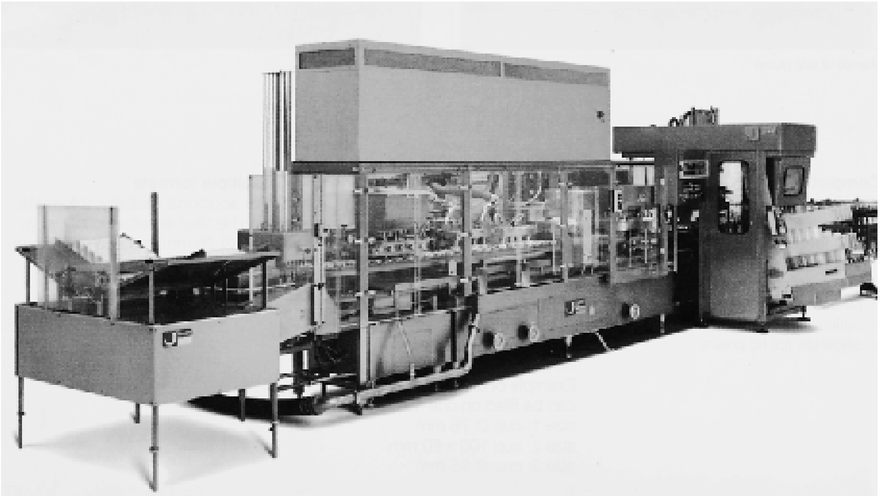


Fig. 3.57 COMBIseptic cup filling machine
Reproduced by courtesy of Jagenberg (London) Ltd., Purley, U.K.

Waldner Dosomat 20 – This is a fully automatic cup filler with a filling capacity up to 60000 cups hour^{-1}. The Dosomat 20 (Hermann Waldner GmbH, Germany) has an automatic cup feeder and filled cups are nested in trays or cardboard boxes. The filler is long enough for the cup loading section, production area and the final packaging section to be separated from each other, thus providing an ideal hygienic layout.

H_2O_2 is used to sterilise the plastic cups but, in the Dosomat 20, rather than spraying H_2O_2 into an air stream, it is vaporised using a special evaporator. Subsequently, the vaporised H_2O_2 is mixed into a hot air stream and blown into the cups through special pump nozzles. This system ensures good wetting of the cup surfaces without forming drops and has another advantage in that, as the optimum reactive temperature is used, there is no need of an unnecessary supply of hot air. Then the cups are dried with hot air on three other stations and the air charged with H_2O_2 is discharged over a catalyser into the open.

All the subsequent stations for filling and sealing the cups are located in a hermetically sealed environment which is flushed continuously with sterile air to minimise recontamination of the cups or the product. The dosing unit is piston driven with outlet tappet valves. A sterile valve junction before the dosing unit, which is hermetically sealed, also ensures that the unit is free from recontamination even after running the filler for a long time. UV irradiation is used to sterilise the aluminium foil lids; alternatively, infrared or H_2O_2 sterilisation systems could be used.

Remy 900 volumeter – This type of yoghurt filling machine can be ordered in three versions, clean with laminar flow, ultraclean and aseptic. In general, the machine offers high standards of hygiene, and in particular:

- An automatic cup loader and dispensing unit
- In the ultraclean version, the cups are sprayed with H_2O_2, dried with sterile hot air and then filled with yoghurt in a sterile, laminar air flow cabinet; in the aseptic

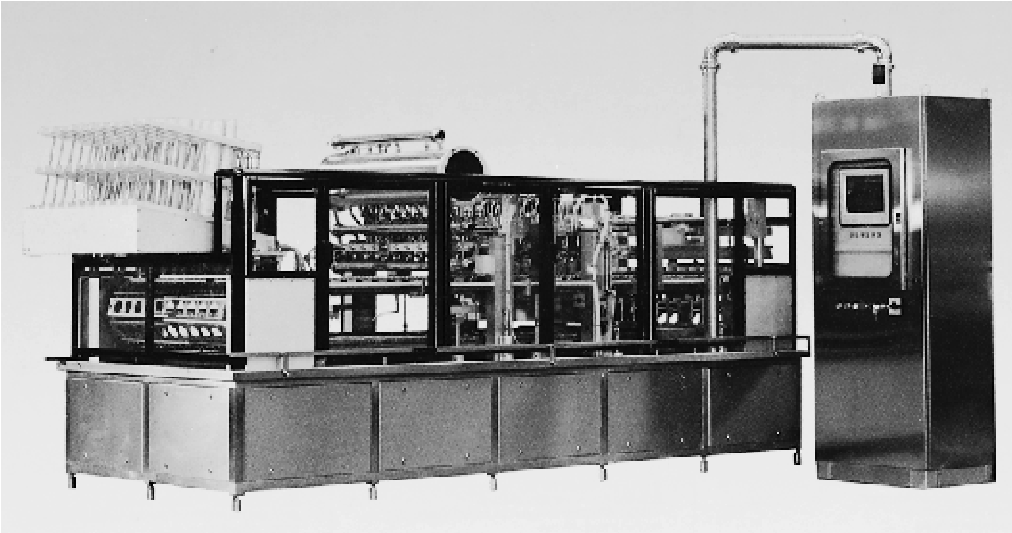


Fig. 3.58 A general view of ILPRA® fill seal 20 000 – the basic model
Reproduced by courtesy of ILPRA SpA, Corso Pavia, Italy.

version, the filling station is equipped with a sterile water barrier, and both the cups and foil lids are sterilised and conditioned inside a sterile watertight tunnel.
- The lids are heat sealed and the filled cups are fed to an automatic tray packer.

The capacity of the machines ranges between 8000 and 54 000 cups hour^{-1} depending on the number of filling lanes. The maximum diameter of the flanges that can be installed are 81, 85, 120 and 150 mm. Incidentally, these machines can be used to fill yoghurt into glass jars too.

ILPRA® Fill Seal System – A wide range of cup filling machines are manufactured by ILPRA SpA in Corso Pavia in Italy and the smaller machines have an output ranging from 1500 to 6500 cups hour^{-1}. However, the larger filling machines (i.e. models 10 000 and 20 000) have a throughput of 11 000 and 24 000 cups hour^{-1}, respectively (see Fig. 3.58). The filling quantity ranges between 50 ml and 500 ml, and both machines may be obtained in different versions: (a) basic, where the cups and the aluminium foil are not sterilised prior to filling, (b) steam cleaned, including a sanitisation system for the packaging materials and where the filler is enclosed within a laminar flow compartment, and (c) aseptic type which is similar to (b) but the cups and foil are sterilised with hydrogen peroxide (H_2O_2).

These filling machines (e.g. models 10 000 and 20 000) have four or ten filling lanes, respectively, including cup holder, destacker, volumetric product dosing head that is suitable for CIP and a heat sealer. The filling machines are equipped with a detector device (e.g. no cup/no fill), a coder station and ejection station. Some other optional facilities include snap-on lid applicator, foil dispensing from a reel for multicups (e.g. 12, 16, 20 or 24) nesting in cartons, plastic trays or boxes.

Hittpac AKH-051 series – These are versatile rotary yoghurt cup fillers for packaging singles including twin-chamber and multipacks of 2, 4 or 6 (see Platt, 1990). The Hittpac AKH-051 series (Lapp-Textima AG, Switzerland) can handle 3000 up

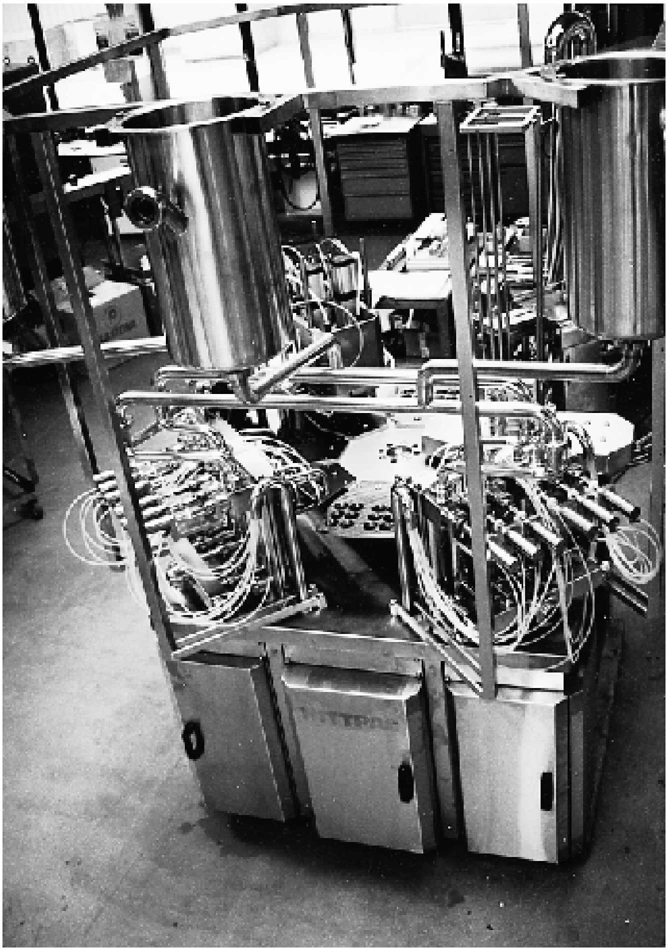


Fig. 3.59 View showing the rotary Hittpac AKH-051 series cup filler
Note the two × 6 cup pocket for multipack yoghurts.
Reproduced by courtesy of Corporation Packaging, Farnham, U.K.

to 15400 and/or 25000 cups hour^{-1} using up to 12 individual pockets per cycle, and for "Petite Suisse" using the SU 8/8 model. The volumetric dosing station has an air brush or membrane nozzle for positive cut-off of the yoghurt to minimise drips between the pots. The fillers are available as aseptic or ultraclean version using hygienic technologies such as UV irradiation or H_2O_2 treatment with hot sterile air (see Fig. 3.59).

Trepko cup filler – High speed 4-, 6- or 8-lane filling machines are made in Denmark and the filling capacity ranges between 10000 and 20000 cup hour^{-1} (see Fig. 3.60). The most basic versions are for filling the plastic containers to be heat sealed with aluminium foil, but most models could be supplied with the facility for UV irradiation of the packaging materials (e.g. cups and foil) and the product filling zone is provided with sterile air in a laminal flow cabinet (see Fig. 3.60). Some cup filling models could be provided with facilities for handling:

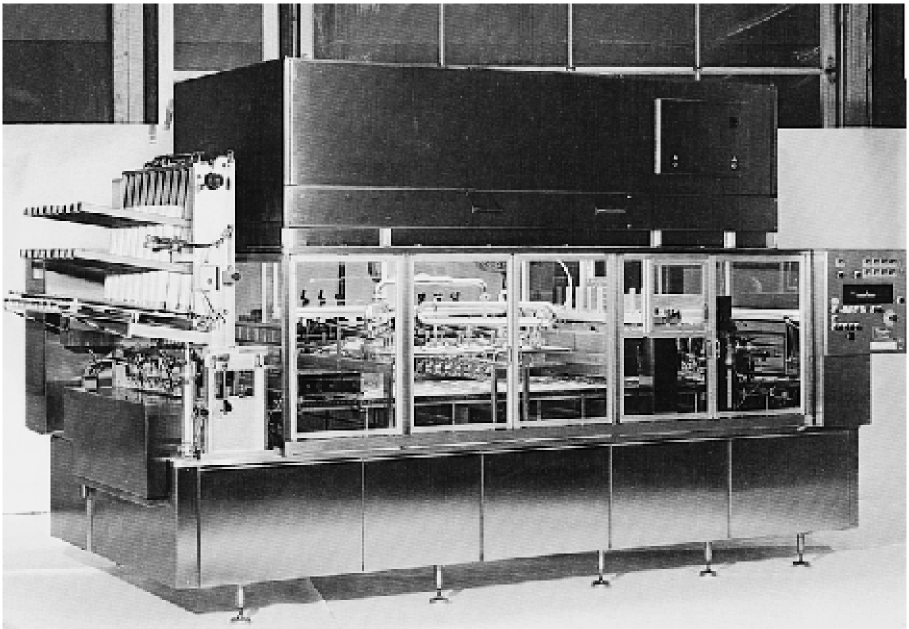


Fig. 3.60 An eight-lane Trepko cup filler
Reproduced by courtesy of Trepko Fyldemaskiner A/S, Taastrup, Denmark.

- snap-on plastic lids
- heat sealing with aluminium foil only, or
- heat sealing plus a snap-on plastic lid.

The cup feeding magazine contains enough cups for up to 5 min operation depending on the cup size, and Hansen (1984) described a four-lane Trepko filler which can be adjusted for four different cup sizes.

Some other features of the Trepko fillers are: (a) a safety cabinet is provided which complies with EU regulations for safety of the machine operators, (b) some models are suitable for filling twin-chamber containers, (c) sensors to detect faulty aluminium foil seals can be supplied, (d) special filling nozzles with membrane valves suitable for filling drinking yoghurt are available, and (e) the machines are designed for CIP cleaning. However, small cup filling machines are also supplied by Trepko, with the filling speed ranges between 2000 and 5000 cups hour^{-1}.

DOGAseptic series – These fully aspectic cup filling machines (Benz & Hilgers GmbH, Germany) are manufactured in different sizes to meet the demand of customers. The overall specifications are given in Table 3.5.

An illustration of such a machine is shown in Fig. 3.61, where the plastic container (before filling) and the aluminium foil lid (before heat sealing) are sterilised by H_2O_2. The sterilised packaging material is then exposed to hot air so that the sterilant is vaporised and exhausted into the atmosphere; filling of the containers takes place in a pressurised, sterile air compartment. The entire filling machine is cleaned by CIP (i.e. circulation rate 30 m^3 hour^{-1} at 0.3 MPa pressure) and the filling head can be steam sterilised at 143°C. Also, the machine is fitted with a cup leakage sensor to ensure proper closure of the containers.

Table 3.5 Overall specifications for DOGAseptic series yoghurt-filling machines

DOGAseptic model	Number of filling lanes	Output (cup hour^{-1})	Maximum cup sizes (mm)	
			Diameter	Height
42	1 × 4	9600	115	130
61	1 × 6	14400	95	130
62	1 × 6	14400	75	105
81	1 × 8	19200	75	105
81/2	1 × 8	36500	75	105
82	1 × 8	20000	95	130
101	1 × 10	25200	75	120

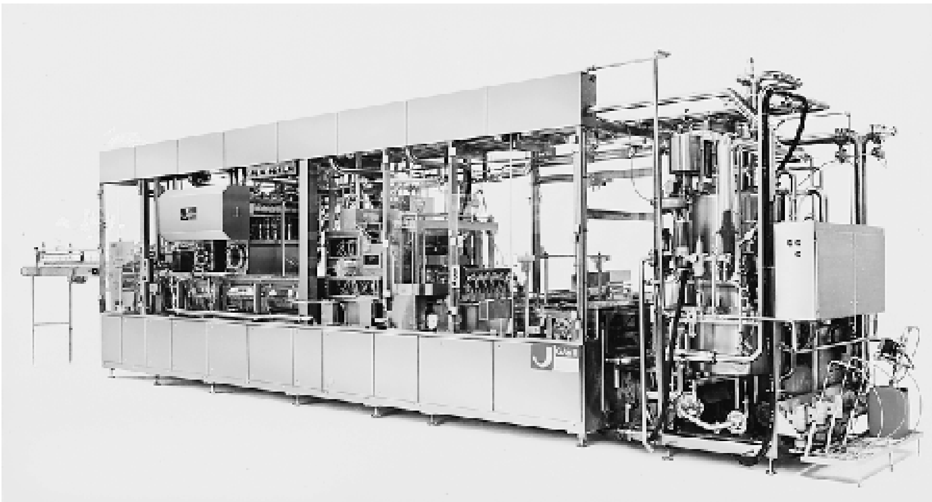


Fig. 3.61 The DOGAseptic 61 which is fully aseptic
Reproduced by courtesy of Jagenberg (London) Ltd., Purley, U.K.

The same company also provides ultraclean or aseptic versions known as SERVOtherm and the output ranges between 38000 and 57000 cups hour^{-1}. These machines can fill and seal tapered cups of all kinds and shapes made of PS, PP, coated paper, coated aluminium and/or other packaging materials.

3.3.11.2 Machines for filling form-fill-seal plastic containers
The packaging material is delivered to the dairy in large reels of plastic sheet and the process of thermoforming transforms the sheet into the shapes and sizes of container required. The finished cartons are then filled with yoghurt and later heat sealed. Some examples of this type of filling machine are as follows.

Hassia THL, THM and TAS models – The thermoplastic material, such as PS, PVC or PP and/or multilayer (e.g. PS/EVOH/PE or PS/PE), is fed from a reel to the preheating section of the filling machine (Hassia Verpackungsmashinen GmbH,

Germany). In this section, contact heating plates with integrated coils are used to provide even distribution of heat; however, for PP packaging material, the preheating station has to be modified to obtain the required temperature for forming the cup(s). Then, mechanical, servo-driven forming plugs prestretch the plastic material to obtain a consistent distribution of the polymer over cup walls and base. The insertion depth of the forming plugs is adjustable so that different cup depths can be made on the same machine. The following stage transfers the containers to the filling head of the machine for filling with yoghurt and heat sealing. A rotary (DDA-CIP) or diaphragm (DMK-CIP) valve filling system is recommended for yoghurt packaging, whilst for two to six multiflavour yoghurt packs the flow metering (DMI) filling system is used. Some output figures for the Hassia THM models are:

Model	Cups $hour^{-1}$
17/28	12000
18/42	21600
28/48	32400
33/80	57600

Other features of the Hassia filling machines are:

- Numerous designs of cup opening features (e.g. unsealed area, corner break-off, raised or recessed unsealed tab) are available.
- The lid material can be heat-sealable lacquered or coated aluminium foil, PS 80–130 μm, PE or multilayer material such as kraft paper (45 $g m^{-2}$) or PETP (12 μm) and metalised lacquer (3 $g m^{-2}$).
- Labelling systems for form-fill-seal cups are available to coat one, two or three sides or all around the cup.
- For extended shelf life products, UV irradiation, pressurised sterile air tunnels or laminar flow cabinets provide a clean packaging environment, whilst steam is used in aseptic machines (see Fig. 3.62).

IIllig FS 37 and FS 51 AS – Thermoplastic material (e.g. PP and/or PS) is fed from a reel to the heating section of the filling machine and the warm sheet is formed into coherent containers after being stretched over a mould; the cup shape is obtained by forcing the plastic into the mould with compressed air. The formed containers, as well as the lid material which is also fed from a reel, enter the sterile bath of H_2O_2 and then a hot air section. All this takes place in a hermetically sealed tunnel to ensure maximum sterility (e.g. guaranteed sterility is at a level of one microbial survivor in 10000 cartons) and the residual H_2O_2 is $<0.1\,\mu g\,g^{-1}$, whilst the concentration of peroxide vapour is about $1\,\mu g\,g^{-1}$.

The Illig FS series machines (Adolf Illig Maschinenbau GmbH, Germany) are available with output capacities ranging between 2000 and 40000 cups $hour^{-1}$ (see Fig. 3.63). These packaging machines use a special DK 300 filler which is aseptic, in order to ensure that the yoghurt can be packed in an absolutely germ free environment. The filler is mounted independently into the filling line.

After filling the cups with yoghurt, the containers are heat sealed and labelled. For example, if there are multipacks of 1×2 or 2×2, the container labels are applied to the front and back of the set pack. Finally the containers are arranged in rows to be transferred into boxes.

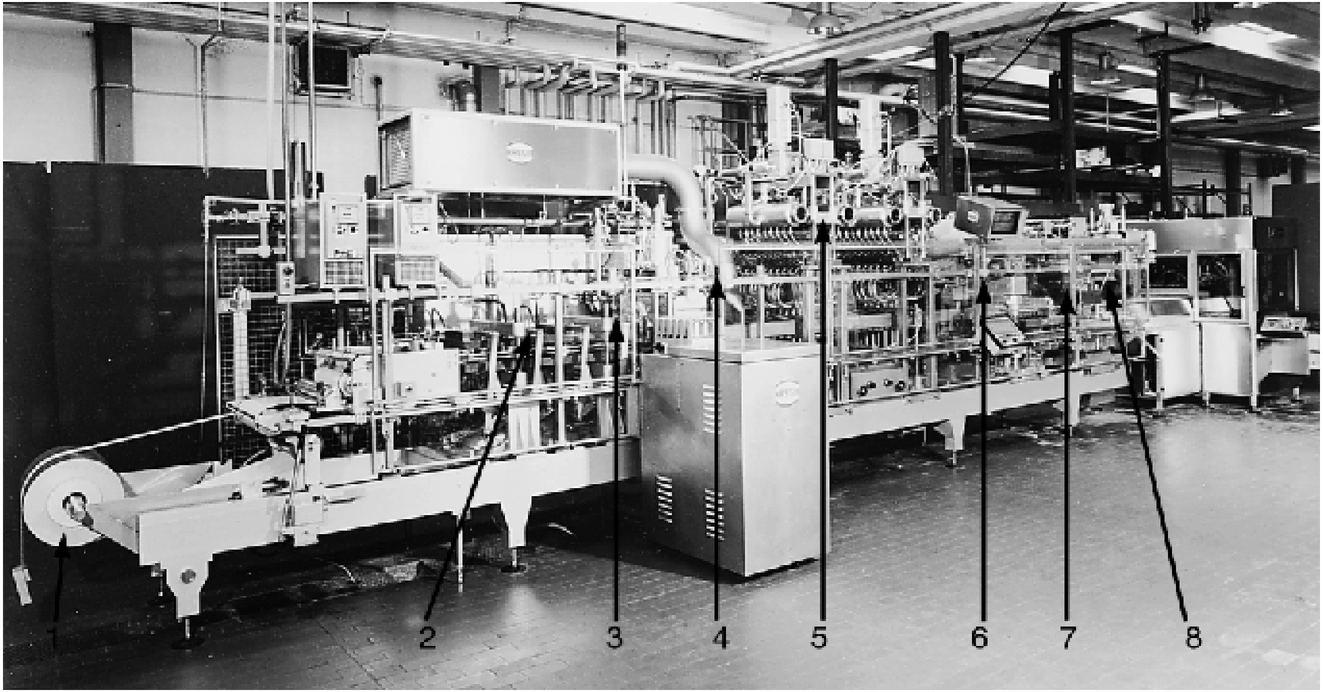


Fig. 3.62 The Hassia TAS 28/48 steam/aseptic system

1, Plastic reel; 2, preheating station; 3, thermoforming unit; 4, cup sterilisation; 5, product dosing unit; 6, steam to sterilise lid material; 7, cup sealing; 8, cup(s) punch.

Note that: (a) Saturated steam of food quality is used at 0.8 MPa pressure, (b) base materials are PS or PVC up to 700 μm thick or multilayer (e.g. PS/PVDC/PS or PS/EVAL/PS), and (c) lid materials are lacquered aluminium foil (30–40 μm thick) or aluminium laminate (PET/A1).

Reproduced by courtesy of Hassia Verpackungsmaschinen GmbH, Hessen, Germany.

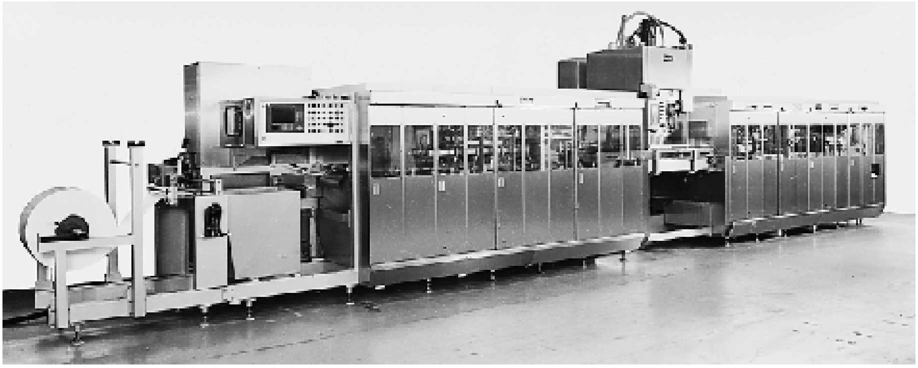


Fig. 3.63 The Illig FS 51 aseptic filling machines
Reproduced by courtesy of Adolf Illig Maschinenbau GmbH, Heilbronn, Germany.

Erca-Formseal (EF) – A versatile range of form-fill-seal machines is produced by ERCA S.A. in France within the Jagenberg group. These machines are supplied in different versions such as: (a) basic (i.e. ambient condition plus a laminar flow cabinet), (b) ultraclean (e.g. as in (a) plus infrared irradiation of lids, UV irradiation or H_2O for material decontamination and/or sterilisation, and (c) fully aseptic which have similar provisions as in (b) and a Neutral Aseptic System® (NAS®) that has provision for presterilising materials using chemicals, steam or UV irradiation. Some specifications of the various EF models are:

Model	Output (125 ml cup $hour^{-1}$)	Number of lanes
300	9000	2 × 3
320	13500	2 × 4
480	20000	2 × 6
	36000	4 × 6
600	28000	2 × 8
	48000	4 × 8
825	40000	2 × 12

However, other features of the EF machines may include: (a) no labelling provided (only on 300 model); alternatively, the label may be partially or fully wrapped around the cup, (b) many different lidding materials can be used, and (c) integrated tray packer, slip-on-lids and rapid cutting tool (see also Anon., 1982; Parr, 1985).

Bosch – Robert Bosch GmbH in Germany manufactures a wide range of filling machines using the form-fill-seal technique. These machines utilise the concepts of ultraclean and/or aseptic technologies; also some models have very high output capacities reaching 100000 cups $hour^{-1}$. Thermoforming plastics which can be used for forming the yoghurt cup are single layer of PS or multilayers consisting of PS/PVDC/PE, PS/PVDC/PS or PS/EVOH/PE. However, the lid packaging material consists of aluminium foil laminate (40 μm) which is soft, smooth, glossy and heat sealable containing lacquer of $8\,g\,m^{-2}$.

A summary of some of the machine specifications of the various Bosch fillers may include the following:

Model		Type[a]	Output (cups $hour^{-1}$)	Number of lanes
TFC	7017	B or UC	24000	–[b]
	7027	B or UC	36000	–
	7033	B or UC	48000	–
TFA	242	A	42000	4 × 5
	2520 (EU)	A	42000	4 × 5
	4940	A	100000	48 cups per cycle
Servac 78		A	48000	Flexible

[a] B: basic (open with laminar flow); UC: ultraclean (enclosed with sterilisation facilities); A: aseptic filling (enclosed where packaging material is sterilised with H_2O_2 and the filler with steam). [b] Not reported.

3.3.11.3 Machines for filling yoghurt into cartons/paper containers

Cartons coated with a layer of polyethylene are widely used in the dairy industry for packaging liquid milk. They can also be used for packaging yoghurt; a slight modification of the filling head is necessary to avoid reducing the viscosity of the yoghurt. As mentioned in Chapter 2, the containers are either formed from a reel (form-fill-seal) or from collapsed/folded preformed cartons. Some examples of carton filling machines are as follows.

Tetra Rex (TR/7 HH & ESL) – These machines are produced by Tetra Pak in Sweden. The container is formed from collapsed/folded preformed cartons (capacities range between 150 and 1130 ml). The sequence of operations for erecting the carton and filling with, for example, yoghurt is given in detail in Fig. 3.64. Some models have an output of 13000 cartons $hour^{-1}$ and, as an option for large size cartons, a plastic insert can be fitted that has a reclosable plastic spout. A similar gable-top carton with a Cap-Pac® spout is available from Nimco or ELL (Evergreen™) in the USA.

Elopak/Pure-Pak – Currently these gable-top carton filling machines are produced in Norway (see Wolthuys, 1986); some models, for example the UH-25, are of an aseptic type (Anon., 1997) and a screw-cap applicator can be supplied.

The Pure-Pak P-S50 filling machine handles a wide variety of cartons from 250–1000 ml and the sequence of operations could be described as follows:

- The blanks are picked from the bottom of the magazine and fed onto a set of mandrels mounted on a hub.
- The carton base is formed and sealed on the mandrels. This is done in four stages: prefolding, heating, folding and sealing.
- The cartons, which now have the base sealed, are drawn off the mandrels and placed into pockets in a conveyor chain. The conveyor is double indexing, which means that the various operations like folding, filling and sealing are done simultaneously on two cartons.
- The two cartons are filled simultaneously in a bottom-up filler specially developed for high viscous products. The filler ensures gentle handling of the product and reduces viscosity loss to a minimum.
- The tops of the cartons are heated.
- The tops are folded and pressed together with water-cooled sealer jaws.
- The filled and sealed cartons are discharged from the machine onto a conveyor and passed on for loading into transport containers.

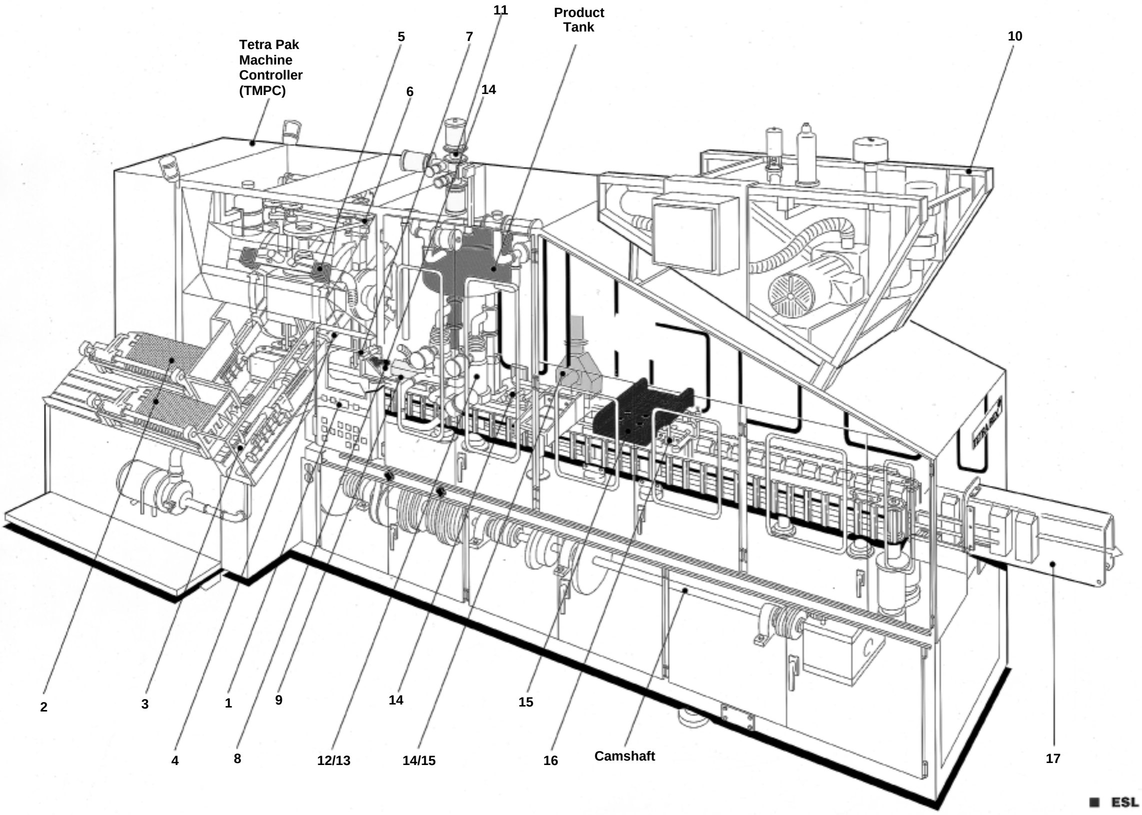


Fig. 3.64 Schematic illustration showing the packaging of yoghurt in a Tetra Rex machine

1, Operator panel; 2, cartons are fed from two horizontal magazines; 3, cartons are erected using suction cups and a pusher arm; 4, cartons are fed onto two temperature-controlled mandrel wheels and carton bottoms are prefolded; 5, prefolded bottom flaps are heated with air from electric ovens; 6, pressure pad completes the bottom seal; 7, carton unloader removes the bottom-sealed cartons from the mandrels and places them on the conveyor; 8, carton interior is sprayed with a 0.1 g 100 ml^{-1} concentration of hydrogen peroxide; 9, cartons then pass through a germicidal, high intensity UV light chamber; 10, sterile air system (SAS) provides over pressure of sterile air to the product fill zone and product tank to prevent outside air from entering; 11, an aseptic product valve (APV) cluster allows for CIP with no break in the product line; 12, cartons pass under the product tank where metering pumps and filling nozzles operate in a sterile air environment; 13, cartons pause briefly and are filled through the bottom-up filling process; 14, moving to the sealing area, the top-sealing heater heats the prefolded carton tops with air from electric ovens; 15, top sealing is completed by pressure from water-cooled sealing jaws; 16, with the package securely sealed, a date stamp is applied; 17, packages are placed on the discharge conveyor.

Reproduced by courtesy of Tetra Pak (U.K.) Ltd., Uxbridge, U.K.

Tetra Brik – An example of a cartoning machine that forms-fills-seals the containers from a laminated paper board reel is the Tetra Brik system that comes as a basic (TB) or aseptic (TBA) version (Tetra Pak, Lund, Sweden). Detailed operation of the Tetra Brik filling machine is illustrated in Fig. 3.65. The output capacity of TAB/21 can reach 8000 cartons $hour^{-1}$ (125–330 ml capacity) or 7000 cartons $hour^{-1}$ (355–1136 ml capacity).

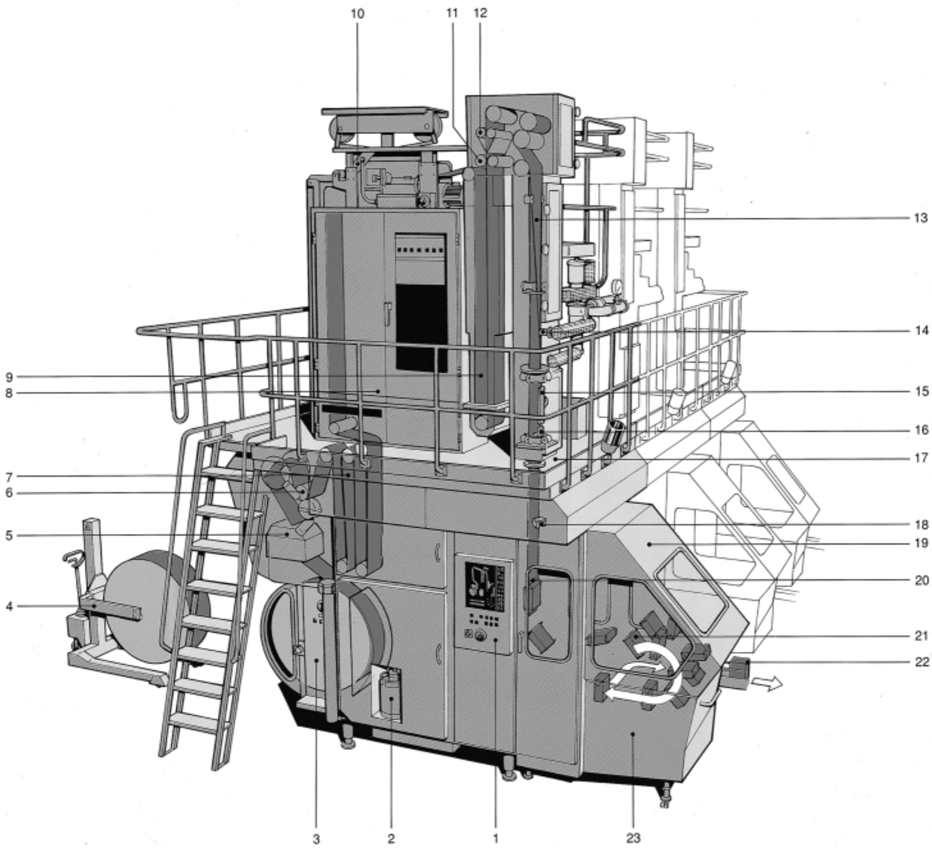


Fig. 3.65 Description of machine operation of form-fill-seal system using the Tetra Pak filling machine

1, Control panel; 2, container for H_2O_2, closed system; 3, reel of packaging material; 4, special trolley with hydraulic lift for handling packaging material; 5, automatic splicing equipment for packaging material; 6, date-stamping unit; 7, loops of packaging material, to ensure smooth, jerk-free feed and also to allow continuous production when new packaging material is spliced in; 8, most of the machine's electrical system is located here; 9, packaging material is sterilised in a deep bath of heated hydrogen peroxide; 10, strip applicator which applies a plastic strip to one edge of the packaging material. Later, at the longitudinal sealing stage, this is welded to the opposite edge. The result is a tight and durable seal; 11, rollers which remove the hydrogen peroxide from the packaging material; 12, nozzles for hot, sterile air, to dry the packaging material; 13, packaging material starts to be shaped into a tube here; 14, filling pipe; 15, element for the longitudinal seam which welds together the two edges of the packaging material; 16, short-stop element which completes the longitudinal seam when the machine restarts after any brief halt in production; 17, TBA/9 is designed so that two or more machines can be linked to form compact production units, sharing a common platform; 18, photocells, which control the machine's automatic design correction system; 19, casing which can be raised and lowered, covering the automatic external cleaning system and the final folder, where the top and bottom flaps are folded over and sealed onto the package; 20, packages are sealed beneath the surface of the liquid using induction heat. The heat comes from jaws which also shape and cut off the packages; 21, in the final folder the top and bottom flaps are sealed onto the package in two lines; 22, discharge of finished packages; 23, bath which fills with water and detergent automatically for external cleaning of the machine.

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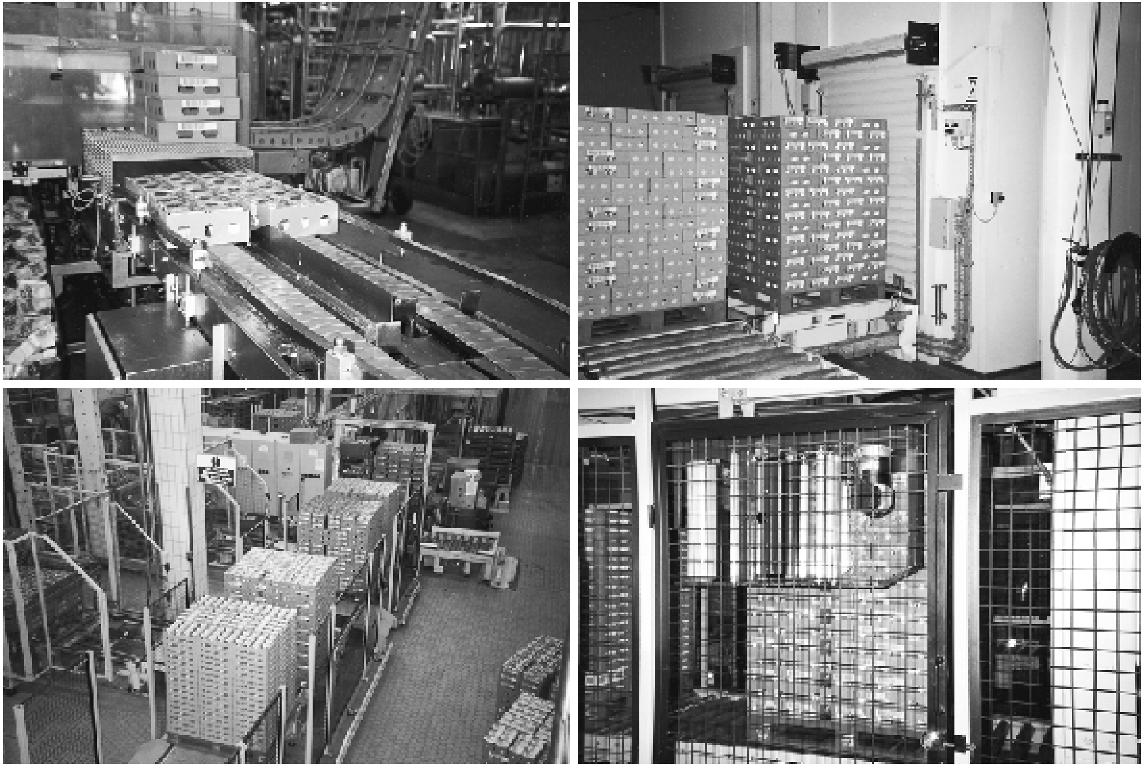

(A) (C)

(B) (D)

Fig. 3.66 On-site automated handling of packaged yoghurt at the Müller factory in the U.K.

A, Nesting yoghurt cups in cardboard boxes; B, palletising the cardboard boxes; C, quick chill cooling in a tunnel; D, plastic overwrap of pallet.

Reproduced by courtesy of Molkerei Alois Müller GmbH & Co. (U.K. Production), Market Drayton, U.K.

The available methods of opening the Tetra Brik carton are: (a) cutting open, (b) opening by tearing along a performation (e.g. wave shaped or high-fin types): both systems produce a spout for poring, but the high-fin perforation makes it easy to reseal the package once opened, (c) applying a drinking straw to <500 ml cartons or pull-tab to any capacity carton, and (d) ReCap® opening (resealable plastic cap). In the latter opening system, the ReCap® lids are delivered in cardboard boxes and loaded into the magazine, which holds two boxes, equivalent to approximately two hours of production. The ReCap® lids are then automatically fed from the boxes in sheets which are cut apart in two operations. The ReCap® lids are fitted and transported by a vacuum chain to the wheel applicator, where a thin layer of hot melt is applied. The ReCap® lid is then fitted exactly over the premade pull-tab opening and held there until the glue has solidified.

3.3.11.4 Machines for filling yoghurt under controlled environment
Some packaging machines are equipped for, or have the facility for, gas flushing of the containers of fruit yoghurt before sealing. The objective is to replace the oxygen in the head space of the carton with carbon dioxide or nitrogen and so restrict the growth of yeast and moulds. Such an approach may indeed extend the shelf life of the product, but it is important not to overlook the facts. First, the packaging materials must be impermeable to these gases and second, the process of gas flushing is only effective against obligate aerobes.

3.3.12 Miscellaneous handling, chill cooling and refrigerated cold storage

The temperature of fruit flavoured stirred yoghurt after packaging in plastic containers may be about 20°C. In large factories, handling the yoghurt until it reaches the cold store may be governed by the plant design or layout and the degree of automation employed for materials handling. A highly automated example could consist of the following steps:

- The yoghurt cups are nested in cardboard trays.
- The stacked trays are palletised (see Cazanave, 1987; Anon., 1991; Hartman, 1995).
- The palletised yoghurt is chill cooled and then secured with a plastic wraparound the pallet to ensure safe handling in the cold store and during distribution and retailing.

Figure 3.66 shows how the packaged yoghurt is handled at Molkerei Alois Müller GmbH & Co. (UK Production), Market Drayton, U.K. The quick cooling of yoghurt is important if it is to retain its consistency after cold storage and the cooling tunnel which is manufactured by KTW Anlagenbau GmbH, Stuttgart in Germany is an example of this approach. According to Anon. (1996 g), ten pallets of set-type yoghurt at 44°C can be cooled in one hour to 7°C (±2°C). Afterwards, the palletised yoghurt is overwrapped with a plastic sheet, transferred to the cold store and a robotic fork-lift system is used to stack the pallets in the cold store.

3.4 Mechanisation of yoghurt production and plant design

As the scale of yoghurt production increases, the use of mechanisation to handle the milk and the coagulum becomes inevitable. A wide range of equipment is

available, but the final choice is governed primarily by the method of processing adopted. Table 3.6 lists those items of equipment that might be required for the production of yoghurt from milk fortified with SMP, or alternatively from standardised milk concentrated by evaporation. It can be observed from Table 3.6, that while different equipment is required for the handling and processing of the milk, the process for the production and handling of the coagulum is broadly similar, and it is relevant that this mechanical handling can lead to structural damage to the coagulum. It is evident from the technical aspects reviewed in Chapter 2 and the effect of mechanical handling of the coagulum discussed in this chapter, that the viscosity and/or consistency of the product can be affected. One of the latest publications of the International Dairy Federation (IDF, 1998) gives details of the factors affecting the rheology of fermented milks and dairy desserts (see also Fong *et al.*, 1995; Houska *et al.*, 1996). An illustration of the effect of handling the coagulum on the viscosity of the final yoghurt is shown in Fig. 3.67 (Norling, personal communication; Bylund, 1995), and it is of note that, if the coagulum is handled carefully, the viscosity of the yoghurt recovers rapidly in cold storage, but the power to recuperate is lost when the coagulum is handled roughly.

Another important feature is, of course, the overall plant design, but the permutations available, particularly within existing buildings, means that each plant layout has to be considered in its own right (see Nicolaus, 1987). The different equipment used for the production of yoghurt should be in close proximity, for example, the distance between the fermentation tanks, the cooler and the intermediate yoghurt

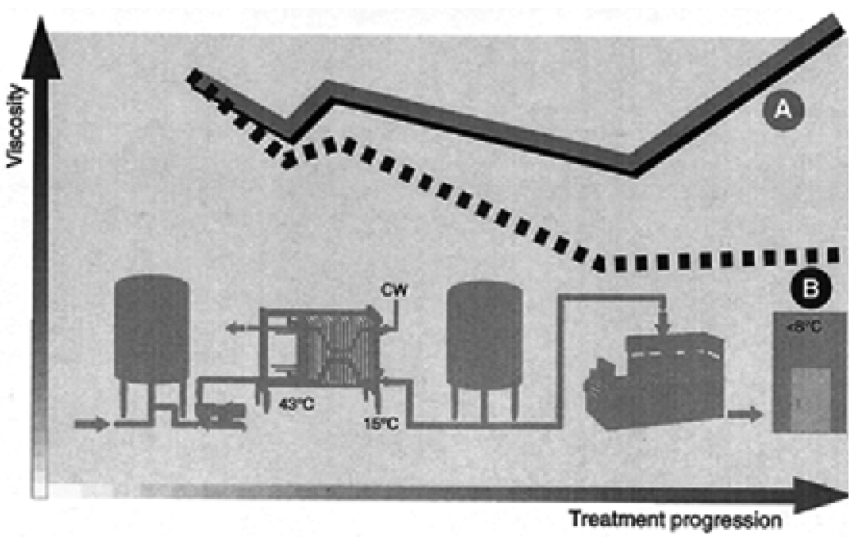

Fig. 3.67 Viscosity curve of yoghurt in relation to mechanical treatments involving sheer stress

A. Optimum plant design; B, badly designed plant.

After Norling (personnel communication) and Bylund (1995). Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund.

Table 3.6 Plant specification of a yoghurt production line – capacity 2000 l hour^{-1}

	Number required	Plant I	Number required	Plant II
Method of fortification		Addition of SMP		Concentration by evaporation
Preliminary treatment of milk	1	Centrifugal pump to circulate milk through powder mixing funnel and storage tanks.		
	1	Powder mixing funnel.		
	2	Vertical storage tanks to hold standardised/ fortified milk.		
	1	Centrifugal pump to pump stored milk to balance tank.	1	as for Plant I
	1	Balance tank for intake of yoghurt milk to the plant.	1	as for Plant I
	1	Centrifugal pump for pumping fortified/ standardised milk to plate heat exchanger.	1	as for Plant I
Processing of milk	1	Plate heat exchanger capacity 2000 l h^{-1} to heat treat milk and cool it to incubation temperature.	1	as for Plant I
	1	Holding tube to hold the milk at heat treatment temperature for at least 3 min.	1	as for Plant I
	1	Homogeniser (capacity 2000 l h^{-1}) to homogenise the milk at >60°C.	1	as for Plant I
	1	Hot water unit to provide thermal energy required to heat milk.	1	as for Plant I
			1	Vacuum chamber to concentrate standardised milk.
			1	Centrifugal pump to pump milk from evaporator to homogeniser, and to recirculate milk to plate heat exchanger until the desired concentration is achieved.
			1	Vacuum pump to pump the condensate from the evaporator to the regeneration section of plate heat exchanger.
			1	Vacuum pump to pump concentrated milk through plate heat exchanger.

	Number required	Plant I	Number required	Plant II
Method of fortification		Addition of SMP		Concentration by evaporation
Starter preparation/ yoghurt production	1	Viscuabator for preparation of mother and intermediate/feeder starter culture.		
	2	Starter vat for the production of bulk starter culture.		
	1	Positive displacement pump to pump bulk starter to the yoghurt incubation tank.		
	1	Positive metering pump for continuous in-line inoculation of milk with the bulk starter culture for production of either stirred or set yoghurt.		
	4–5	Vertical incubation tanks, each with a capacity of 2000 l; and/or incubation cabinets/tunnel to produce set yoghurt where the number is dependent on method adopted.		
	1	Positive displacement pump to pump the yoghurt coagulum to plate cooler.		
	1	Plate heat exchanger (capacity 4000 l $hour^{-1}$) to cool yoghurt.		
	1	Cold water unit to cool yoghurt.		
	1	Centrifugal pump used as a by-pass to pump recirculated water on the cold water side.		
Fruit blending/ packaging	2	Vertical intermediate storage tanks, each with a capacity of 3000 l depending on production schedule.		
	2	Positive displacement pumps (metering type) to pump yoghurt and fruit flavours to the blending unit.		
	1	Fruit/yoghurt blending unit.		
	1–2	Yoghurt filling machine(s) of total throughput 2000 l $hour^{-1}$.		
CIP system	1	Control panel.		
	3	Tanks for detergent solutions.		
	4	Liquid ring pumps used as return pumps for cleaning.		
	1	Plate heat exchanger to heat detergent solutions.		
	1	Centrifugal pump used as feed pump for detergent solution.		
	1	Filter to remove large soil particles from the CIP system.		
	1	Steam controller.		
Miscellaneous	1	Main control panel.		
	–	Number of valves, fittings and pipes required in each of the sections mentioned above.		

Data compiled from Tetra Pak A/B technical specification of yoghurt plants.

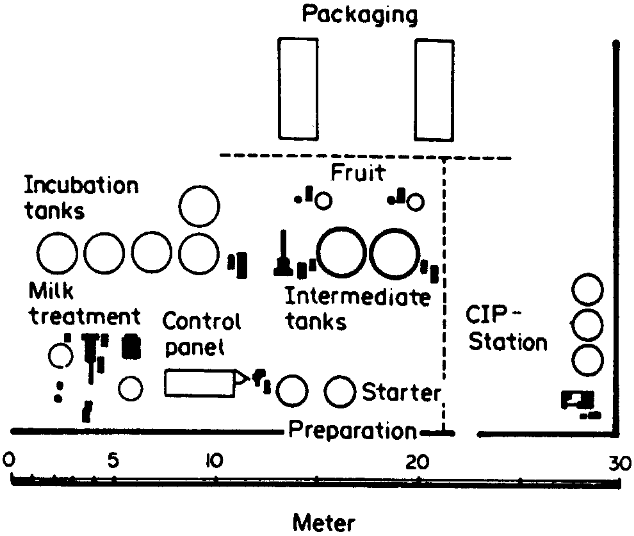

Fig. 3.68 Layout of a yoghurt plant to handle 3000–40001 hour^{-1}

Space requirements for some Tetra Pak yoghurt plants based on the layout above; excluding the areas required for the CIP unit and the packaging machinery are:

Plant capacity ($l\,h^{-1}$)	Floor area (m^2)
1000	16 × 10 = 160
2000	18 × 11 = 198 (200)
3000	20 × 12 = 240
6000	25 × 12 = 300
10 000	26 × 13 = 338 (340)

Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Lund, Sweden.

storage tank(s) should be as short as possible. In some instances, the equipment has to be installed in an already existing building (which could be a limiting factor), but considering the recommendations mentioned earlier, the reduction in viscosity of the yoghurt could still be minimised. In an ideal situation (i.e. factory construction and plant installation carried out simultaneously) the layout of a yoghurt plant might take the form illustrated in Fig. 3.68. Notice that the flow of yoghurt from the incubation tanks to the cooler and storage tanks is virtually in a straight line and that the distance is short. The situation is similar for the transfer of yoghurt from the storage tanks to the filling machines.

Finally limited data are available on the physical damage experienced by yoghurt during transport; the effect of vibratory motion on packaged yoghurt has been examined by Richmond *et al.* (1985), who reported the following categories: (a) slight or definite, (b) cracked coagulum, and (c) complete disruption of the coagulum. The same authors also reported that the top layers of the vibrated stack (i.e. 10 high) were most damaged, and they found that overwrapping the shipping containers with polythene proved most effective in reducing syneresis; <1% of containers wrapped in this manner had cartons showing any sign of syneresis (see also Fig. 3.66).

3.5 Continuous yoghurt production

3.5.1 Background

In practice, the expression continuous production of set and/or stirred yoghurt is taken literally to mean the continuous flow of coagulated milk, and this can be achieved by employing a high degree of mechanisation and an appropriate plant design. For example, if a series of incubation chambers and/or fermentation tanks are used at regular intervals, the result is, in effect, a continuous production of set and/or stirred yoghurt. However, this constant flow of yoghurt should not really be termed continuous yoghurt production, since the product is still manufactured in synchronised batches and there is almost always some variability in the quality of the end product.

In theory, therefore, continuous yoghurt production should only refer to a process in which the raw material (milk) is steadily and continuously transformed into a coagulum (yoghurt). One of the earliest processes reported for the continuous production of set yoghurt was the method designed by Ueno *et al.* (1966). In this system the inoculated milk is filled into glass bottles, and the stacked crates which hold the bottles are placed on a cradle suspended from an overhead conveyor system. The distance between successive cradles is 60 cm, and the rate of production per hour is dependent on the speed of the conveyor, for example about 14000 or about 18500 bottles of yoghurt at speeds of 1.2 or 1.54 $m\,min^{-1}$, respectively. These cradles pass through the incubation chamber in a zig-zag manner up to five layers high and, after a certain duration (depending on the rate of acid development and the incubation temperature), the cradles pass through a chilling room (air temperature at −5°C) which cools the yoghurt to 20°C; final cooling takes place in the cold store. Hansen (1977) described a similar process used in Belgium where special trolleys (each holding 153 trays of cups filled with inoculated milk) are driven by a conveyor belt through the incubation tunnel. At pH 4.5, the yoghurt is passed to an adjacent tunnel which cools the yoghurt from 38°C to 15°C; final cooling takes place in the cold store. Incidentally, the cooling tunnel is divided into four sections and the temperature of the cold air in circulation is successively decreased, that is, starting at 8–10°C and finishing at 4–5°C. Other continuous systems have been reviewed by Rasic (1975) (see also Guyot, 1986).

A continuous process for the manufacture of stirred yoghurt is rather more complex than the systems mentioned above, but Girginov (1965) developed a semi-continuous process for the production of set yoghurt in batches and the basic principle of his technique (i.e. a two-stage fermentation) was later developed for a completely continuous process for the production of stirred yoghurt. The original Girginov method consisted of the following steps:

- Prepare the milk base, i.e. fortify, heat-treat and cool.
- Inoculate the processed milk at 46–48°C with uncooled yoghurt starter culture (42°C).
- Incubate the bulk until acidity reaches 0.23–0.27 $g\,100\,ml^{-1}$ lactic acid.
- Maintain a continuous prefermentation process by the constant addition of processed milk at 46–48°C and simultaneous discharge of an equal volume; thus the volume of milk and the acidity (0.23–0.27 $g\,100\,m^{-1}$ lactic acid) always remain constant.

- Cool the prefermented milk to 32–33°C, fill into containers and incubate to the desired acidity.
- Cool the yoghurt to 5–6°C, store and dispatch.

3.5.2 The NIZO process

During the early seventies, a research team at the Netherlands Institute for Dairy Research (NIZO) developed a continuous yoghurt making process based on the same two-stage fermentation, that is, the prefermentation (pH-stat) stage followed by the coagulum formation (plug-flow fermentor) stage. A flow diagram of this process and the recommended conditions for a laboratory and a pilot-scale plant operation have been well documented by Anon. (1975a) and Driessen *et al*. (1977a, b) (see also Lelieveld, 1976, 1984; Driessen, 1981). A summary of their observations and recommendations is given below:

- The yoghurt starter culture (RR) is an EPS producer that yields a viscous yoghurt; the ratio of cocci to rods in the starter culture is 1:4.
- The incubation temperature in the prefermentation tank is 45°C; this provides the optimum growth conditions for the yoghurt organisms and the pH of the milk is reduced to 5.7 within 15–20 min. At this pH, the ratio of cocci to rods is around 19:1, but this changes to 1:4 in the final product. This ratio of 19:1 is essential to provide a pH-stat, because the prefermented milk is constantly diluted and, if the specific growth rates altered, the quality of the yoghurt would be affected.
- The phenomenon of syneresis, i.e. whey separation from the yoghurt coagulum, is directly related to the degree of physical disturbance to which the network of the protein micelles is subjected, but it can also be brought about by careless processing of the milk, e.g. poor pH and temperature control during the incubation period. Disturbance of the protein micelles in a continuous process can take place at the following stages: (a) during the prefermentation, i.e. before the final network of the protein has formed, any disturbance of the coagulum below pH 5.7 could cause some damage, (b) during the coagulum formation period the network of protein is being formed and syneresis can occur if the gel is disturbed, and (c) if, after formation of the stable network, the yoghurt coagulum is stirred above pH 4.6, wheying-off can occur.

  Syneresis could, therefore, take place during the second stage of the NIZO process, as stirring of the coagulum is inevitable in a continuous process, and hence avoidance of problems is dependent on the temperature of incubation and the level of acidity. For example, if a temperature of 45°C is used throughout the process, the coagulum cannot be disturbed between pH 5.6 and 4.6 (i.e. the critical zone), while at a slightly reduced temperature of incubation, e.g. 37°C, the critical zone is between pH 5.6 and 4.8. It is for this reason that the prefermented milk is cooled to 37°C before it is transferred to the plug-flow fermentor since, at the higher pH level (pH 5.7), the coagulum can be disturbed without causing any syneresis.
- The dilution rate (e.g. the rate of addition of the milk base to the prefermentation tank) can be increased at higher pH values. This observation is based on the existence of the linear relationship between the concentration of lactic acid and the specific growth rate of the yoghurt organisms under controlled conditions.

Thus, it is recommended that fresh milk is added to the prefermentor at a rate that maintains the pH at 5.7, so ensuring the desired balance between *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* and the subsequent absence of syneresis (see also Lewis, 1967; Meyer *et al.* 1975; MacBean, 1976; Lelieveld, 1976; MacBean *et al.* 1978, 1979).

- The plug-flow fermentor unit is designed to: (a) avoid disturbance of the coagulated milk in the fermentor during the transfer of the prefermented milk, and hence the fermentor is fitted with a special centrifugal distributor (Anon., 1975b), (b) prevent the coagulated milk adhering to the sides of the fermentor, and to this end the tank is coated with polytetrafluroethylene (PTFE) or lecithin, and (c) avoid damaging the coagulum during the stirring and removal of the coagulated milk, and hence the plug-flow fermentor is fitted with a specially designed stirring plate (Anon., 1975a).
- The residence time of the prefermented milk in the coagulum formation unit is $2\frac{1}{2}$ hours at 37°C.
- The development of this process was carried out in equipment capable of producing 2501 hour^{-1}, but the recommended throughput for a large-scale plant is around 40001 hour^{-1} (see also van der Loo, 1981; Fig. 3.69). This industrial size was made available to yoghurt producers, but it could be argued that this technological development was too advanced for acceptance by the industry; however, continuous yoghurt production may become an acceptable process in the future.
- The alleged advantages of continuous yoghurt making are space saving, reduction in size of equipment, reduction of yoghurt losses in fermentation tanks and pipe lines, reduction in capacity of cooling and filling sections, greater flexibility in relation to total amount produced, no need for all the milk to be in stock at

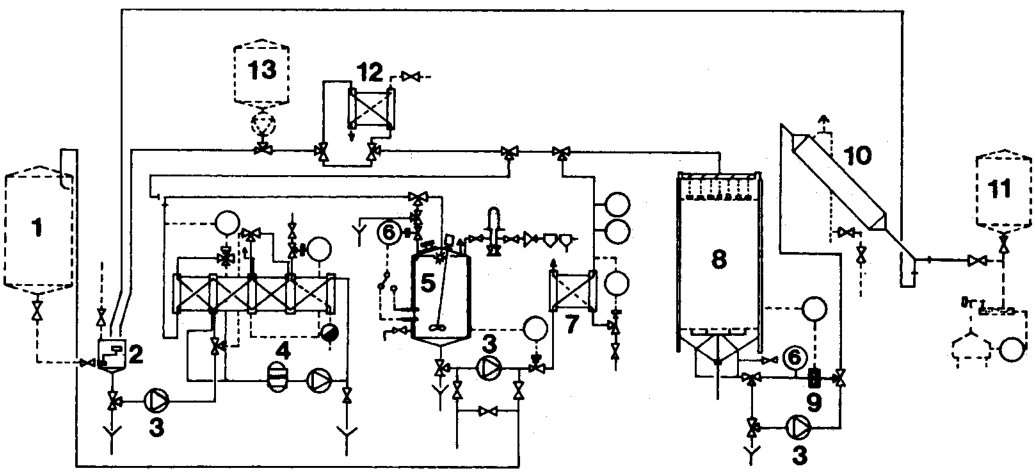

Fig. 3.69 Flow diagram showing the Stork-Amsterdam continuous process line for the production of stirred yoghurt

1, Milk storage tank; 2, balance tank; 3, centrifugal pump; 4, PHE; 5, continuous fermentation tank (pH stat-fermentor); 6, pH controller; 7, cooler; 8, coagulation tank (pH plug-fermentor); 9, positive displacement pump; 10, cooler; 11, buffer tank; 12, emergency cooler; 13, emergency buffer tank.

Reproduced by courtesy of Stork-Amsterdam International, U.K.

the start of production, uniformity of product quality and characteristics, better control over acid development and less pressure on the cooling and packaging operations.

3.5.3 Recent developments

Recent research in the area of continuous yoghurt production mainly involves microbial growth kinetics of fed-batch fermentations (Özadali and Özilgen, 1988) and optimisation and control in fed-batch bioreactors (Shioya, 1992). In both cases the primary objective is to preferment milk in a reactor in order to accelerate yoghurt production. Prevost *et al.* (1985) entrapped the yoghurt micro-organisms on Ca-alginate beads and the rates of cell production (cfu l^{-1} hour^{-1}) for streptococci and lactobacilli were 1.8×10^{11} and 1.6×10^{11}, respectively (see Prevost and Divies, 1988a). The process ensured that a stable balance of *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* was liberated into the prefermented milk, and when such milk was used in yoghurt production, the incubation time was reduced by 15–20% (Prevost and Divies, 1988b).

Otten *et al.* (1995, 1996) used a fed-batch prefermentation of milk over a period of 51 hour with the same yoghurt starter culture without infection or loss of product quality. However, the same authors concluded that: (a) after one inculation of the prefermentation tank at least 20 to 30 large fermentation vessels could be inoculated, (b) by using high inoculation percentages (~15%) of the prefermented milk, the inoculation time of yoghurt production time was reduced by 50%, (c) in such a system there was greater flexibility when compared with a continuous prefermentation (see Driessen *et al.*, 1977a, b) because there was no continuous outlet flow, (d) by using high inoculation rates of prefermented milk, the yoghurt production capacity of an existing plant could be doubled with relatively low capital investment cost, and (e) to maximise profit by this method, the yoghurt manufacturer should operate 24 hours per day.

A continuous yoghurt culturing process has been studied by Ray and Raeuber (1991, 1992). From model equations and laboratory-scale experiments, they showed that constant, high stream velocity and relatively low shear gradient in a tube fermentor facilitated stable and continuous yoghurt culturing, whilst Ho and Mittal (1995) provided five different models (e.g. flow-and-hold and partial-flow-and-hold) or three continuous models (i.e. diversion, feedback and flow control) for continuous yoghurt making. In the former two systems, the flow rate was fast (8.31s^{-1}) and the method required high-powered pumps compared with the other models in which the flow rate was very low (0.071s^{-1}).

Continuous yoghurt production methods using two-step processes consisting of preculturing and main culturing within tube-type reactors have also been reported by Schulze and Raeuber (1993) and Steiner *et al.* (1993). All these researchers have used refractometry, optical sensors and ATR-spectroscopy to monitor continuously casein coagulation as a means of process control.

In the late 1980s, the Terlet company developed equipment for the continuous coagulaton of milk (Boer, 1987). Preacidified milk is delivered to containers (1201 capacity each) that are suspended on conveyor belts which are housed in a vertical tower. The containers advance through the tower at uniform velocity at 45°C for the desired time until coagulation occurs. Afterwards the yoghurt is discharged to a cooling unit.

3.6 Automation/process control

In the past almost all the operations involved in the manufacture of yoghurt, including the cleaning stages, were carried out manually but, as processing plants have become larger and more complex (see Fig. 3.70), management and operators can have great difficulty in overseeing and controlling the process, particularly if the plant is spread over a number of process areas within the factory and/or a factory is producing yoghurt made from different ingredients for different customers. Communication between the various process areas can be difficult and support will be needed to ensure that the process is secure and manageable. This support can only be given by the use of a process control or supervisory system, supplemented by some form of management information system (MIS) (see Section 3.6.8). Such systems tend to be tailor-made for the particular process plant from proprietary components to produce a system which will allow the operators to operate the process and allow the management to control it. Periodically, the International Dairy Federation (IDF, 1973, 1985, 1991, 1995) publishes bulletins on automation in the dairy industry. The reader is referred to these publications for a more complete discussion (see also Mouchet, 1984; Lloyd, 1984; Bylund, 1995). Nevertheless, correct application of automation has many advantages such as:

- Production information for business analysis
- Product quality
- Flexible production
- Production control
- Minimising waste at start-up and shut-down
- Real time scheduling
- Plant maintenance scheduling
- CIP control
- Waste management

Taking these factors into account, the principles of automation as might be applied in a yoghurt factory are described below. The text has been cordially provided by APV (U.K.) and Tetra Pak (U.K.).

3.6.1 Levels of automation

There are various levels to which any process plant can be automated (Bird, personal communication), and these can be summarised as:

- Manual – where the operator is in sole control of the process and initiates all valve changes and tank selections by hand. A low level of automation support will be included.
- Semi-automatic – where the operator is provided with certain functions to assist in controlling the plant, such as flow plates, with proximity switches, to allow a distinct break between process and CIP; high and low level transmitters and gauges on tanks and the necessary switches; remote initiation of the CIP module.
- Fully automatic – where the operator is supported fully by an automation system and all commands are given by an operator control centre, or a number of decentralised operator interface units placed strategically around the process. These systems are usually further supported by an MIS.

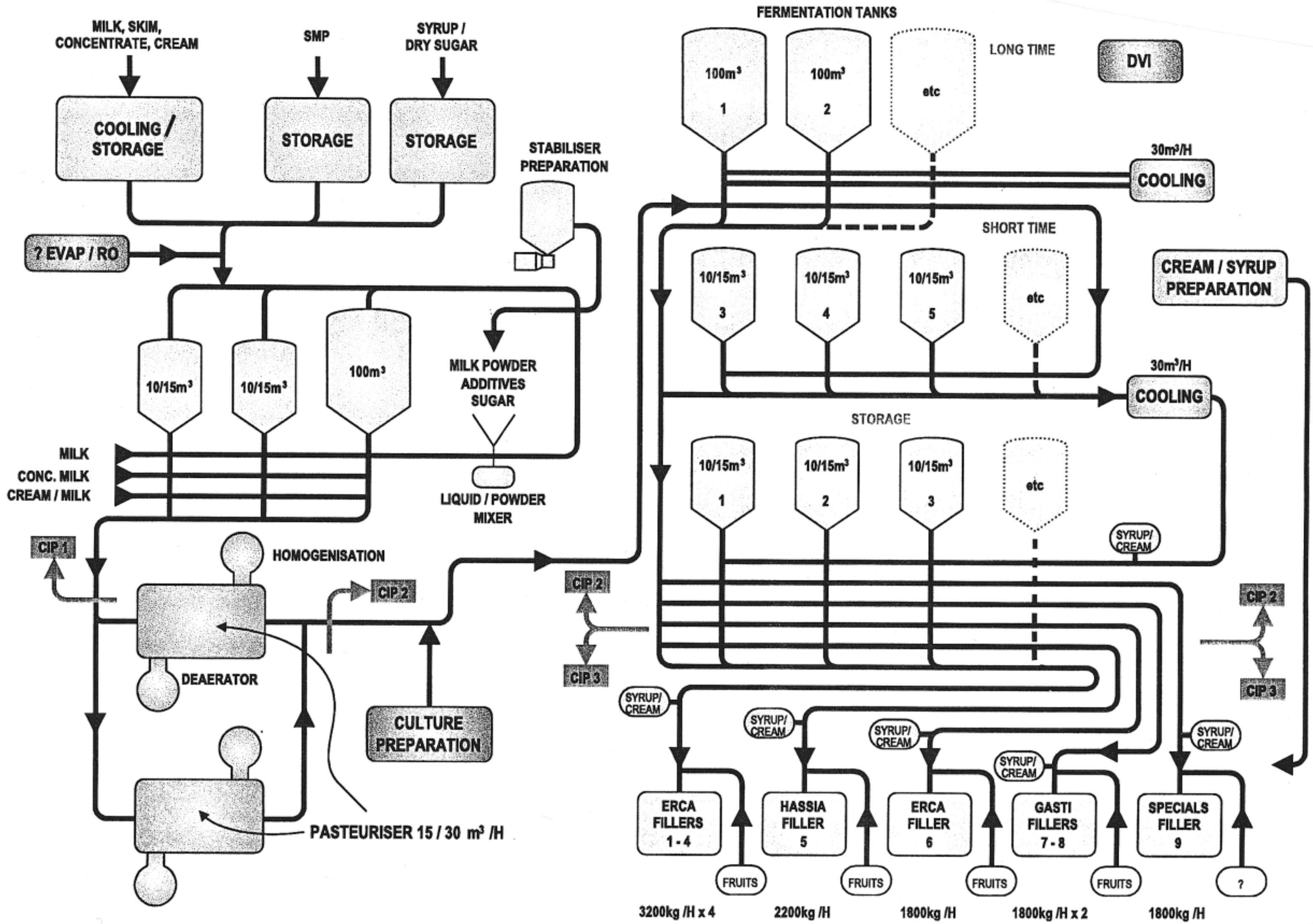

Fig. 3.70 Illustration of a typical stirred yoghurt plant capable of producing 20000 tonnes per annum
Reproduced with courtesy of APV U.K. Co. Ltd., Crawley, U.K.

The choice of which system to install on an existing process plant is dependent on many factors. Cost is an important issue, but the level of automation required to assist the operator whilst still leaving the final control in his or her hands is also important. In other words, too much automation is just as dangerous to a process as too little, for there is a danger that a skilled operator may become complacent if suddenly confronted by a machine which does the thinking. Existing process plants can be automated to a semi-automatic level whilst still allowing all decisions affecting process functions to be in the hands of the operator.

A fully automated system is the highest level which can be installed into a site and is usually offered on new installations. In this instance, the automation concept is just as important as the process context and the design of the two systems is integral. Existing process plants may not be capable of automation to fully automated status without significant capital investment within the infrastructure of the process plant. The degree of automation in a yoghurt plant (see Fig. 3.70) is primarily dependent on capacity but, in the absence of any constraints, the processing plant is divided into different areas/departments interlinked via a central data processing unit. The choice of divisions can be subject to individual choice, but the following break-down would be quite feasible.

3.6.2 Area/department 1

In this area reception and storage of the milk takes place, together with preparation of the basic mix and automation covers handling of the liquid milk, control the flow of milk from the storage tanks, cleaning the tanks, and the selection of the dry ingredients (milk powder, sugar and stabilisers).

According to Bird (personal communication), these requirements can only be met if the process control systems are capable of monitoring and controlling the following functions:

- ingredient receipt
- recipe handling
- product routing and security
- critical process parameters
- disinfection parameters
- service(s) utilisation
- overall process plant performance.

This control is achieved by installing monitoring devices (instruments) around the process plant and taking the signals from these instruments to the control system. The control system will then compare the observed reading against the target reading and take the relevant action. The action may be, for instance, opening a steam valve to heat a CIP detergent tank to the correct temperature, or if a storage silo has reached the full level, automatically selecting the next tank in the queue to be filled.

The activation of a control instruction is normally "flagged-up" so that the operator is aware of what is happening; this is called feedback and is a most important facet of the system. If the operator does not know what is happening within the process, he or she cannot control it. Pipelines and valves are used to route product from one plant area to another, and both the control system and the operator need to be aware of the status of any transport route, particularly the valve positions.

Feedback loops from the valves allow the control system to prove that a route is available prior to allowing the operator to initiate a product or ingredient transfer.

Valves are now designed with this requirement in mind and they normally operate with compressed air driving the valve in one direction and a strong spring driving the valve in the reverse direction. All valves will revert to their rest position in the absence of compressed air and it is an important function of process plant design to ensure that valves are installed correctly. Tank outlet valves, for example, are always air actuated to the open position and spring closed – imagine what would happen if they were installed the opposite way and the compressed air supply failed!

Feedback can be just as important and valve feedback can be set at one of three levels:

- No feedback: in this instance, the valve can function but the control system cannot monitor it. This approach is only used when there is some other signal which allows the control system to monitor the effect of the valve opening. For example, the effect of a steam valve opening can be monitored by a rise in temperature at some point, but this absence of feedback is not normally recommended.
- Single feedback: in this case, the valve is monitored only in one position. When in this position there will be feedback to the control system and depending on the plant design, the feedback position could be normally-open or normally-closed.
- Double feedback: in this instance, the valve is monitored in both the actuated and rest positions. Double feedback is the most expensive system to install as two signals are required from each valve; the choice of single or double feedback requires careful consideration at the initial design stage.

3.6.3 Area/department 2

Milk standardisation, homogenisation and heat treatment take place in this section, and the operating sequence of the heat exchanger unit can be easily programmed to heat the milk to 90–95°C, hold it for the desired duration of time and then cool it to 40–45°C. To achieve this pattern, the plate heat exchanger unit will be fitted with certain controls to ensure that a repeatable and consistent performance is obtained. For example:

- The control system must ensure that the correct temperatures are achieved.
- A diversion mechanism must be in place to pass under-temperature milk back to a holding tank.
- The control system must ensure that milk leaving the heat exchanger is at the correct temperature for inoculation with the starter culture.

It is essential that this section of the plant is effectively cleaned. The CIP module may have a dedicated process control system to monitor and control its functions, such as: (a) checking and adjusting the target temperature of the detergent tank, (b) checking detergent strength measured by the conductivity of the solution and initiating the operation of the detergent dosing pump if the conductivity reading is low, (c) monitoring the return flow, temperature and conductivity of solutions used during a CIP sequence, and (d) initiating valve and pump activity when required by the programme (Bird, personal communication).

3.6.4 Area/department 3

The preparation of the starter culture is carried out here and automatic control systems are able to provide the necessary conditions for growth of the selected culture (see Chapter 8). The in-line inoculation of the process milk can be under the control of the same section.

3.6.5 Area/department 4

In this section, fermentation of the milk takes place and automation covers the control of temperature during the incubation period, monitoring the level of acidity (pH) and initiation of the cooling stage. As with the previous areas, both the operator and the control system must be aware of the status of all the vessels and valves but, equally important, the system must alert the operator if an observed parameter is outside of the target parameter. It has been suggested by Bird (personal communication) that it is usual for the control system to print out the alarm on a printer attached to the system. This will give two levels of information: in the first instance, immediate notification to the operator that something is not correct and that the system is taking remedial action or that the operator should make adjustments to the process, and second, tabulation of a hard-copy of all alarms for future reference. For emergency situations, audible alarms are essential, but in order to anticipate possible problems, operators can derive great benefit from visual displays of the entire process within their section; a number of options are available.

A diagrammatic visual display of the plant is useful so that the operator can observe the status of the process quickly. Such displays may take one of the following forms:

- Mimic panel: this is a diagrammatic display of the whole plant showing process blocks and transport routes. Lights illuminate to indicate to the operator when a component is running or activated, such as a pump or high-level switch on a tank. These displays look impressive to visitors to the plant, but their ability to inform the operator is questionable due to the amount of information displayed. They are also inflexible and cannot be easily updated when changes to the process occur.
- Matrix panel: this is a panel of lights set in a form that will light up when a route is in operation. The object is normally on the horizontal axis and the status – empty, full or under CIP – is on the vertical axis. The status of, say, a tank under CIP will be indicated by a light displayed at the conjunction of the tank reference and plant status. Differing coloured lights can indicate status – green for process, brown for CIP and red for alarms; a flashing light can indicate a queued situation.
- Colour graphics: this is similar to a mimic panel, but the plant is displayed in pages. The initial page will display the whole plant with all ingredient reception lines, tanks, pasteurisation plants and CIP modules. Selecting a plant area will allow the operator to assess the next page where that section of the plant is identified in greater detail. Selecting a plant item will allow the operator to display the status of that item. In the case of a tank, it will indicate the product definition, the extent of fill by a coloured level and whether the tank is filling or emptying. It will also state the volume in the tank and the temperature. The information can be displayed at the click of a mouse.

3.6.6 Area/department 5

In this section, blending of the fruit with white base takes place and since a factory may be manufacturing 15–20 different varieties of yoghurt in a week, automatic monitoring is essential. Thus, there will be different types of fruit/flavours (e.g. strawberry, banana, black cherry and many more), there may be different qualities of each fruit/flavour to meet the specifications set by different retailers and there may be separate formulations of white base for branded or own-label lines. In addition, each variety will require a specific form of packaging. Ensuring that all the possible permutations are covered depends increasingly on computer control.

What these aspects highlight is that the manufacturer is no longer able to operate in isolation and that market forces often have a considerable impact on production. Consequently, the scheduling of different batches of yoghurt has become central to production planning and, since many individual recipe formulations may be produced in parallel within a single process line, there are likely to be many discrete batches passing through a particular plant at any one time. The sizing of batches and their routing through the plant is, therefore, a complex task which can have a major effect on the optimisation of resources and, ultimately, on the profitability of a manufacturing facility (Chester, personal communication). The difficulty of optimising batch scheduling has been exacerbated by the demands of modern sales and marketing requirements and there have been two distinct trends which have had a major impact on processors, namely extension of product ranges and "just in time" delivery.

3.6.6.1 Extended product range

In anticipation of market demands, multiple versions of the same generic products have been developed. These versions exhibit particular features designed to appeal to different market segments and to stand apart from competitors' products. Typical factors upon which products are discriminated include:

- Perceived quality (i.e. high price for high quality and, conversely, supermarket "value" ranges at reduced prices)
- Appeal to different age groups (e.g. cartoon/film related packaging and flavours to appeal to children)
- Perceived health benefits (e.g. low fat versions, different yoghurt cultures)
- Dietary requirements (e.g. vegetarian yoghurts, with no added gelatine)
- Shelf life (e.g. extended shelf life (ESL) and UHT versions)

Owing to their perishable nature, different types of yoghurt must be manufactured frequently. Most factories will manufacture each product several times per week and depending on shelf life, in some instances every day. Thus, where a wide product range is supported, a large number of different batches must be processed simultaneously. In order to accommodate a large number of batches, manufacturing facilities must be equipped with numerous and variously sized storage vessels and a vastly increased number of process routes. The resultant increase in routeing permutations and storage options greatly complicates batch planning and scheduling and, since equipment resources are limited, there is great pressure on the production manager to optimise batch scheduling to maximise their use whilst, at the same time, meeting production demands.

3.6.6.2 Just in time delivery

Driven by the desire to extend the shelf life of goods bought by the consumer (so increasing sales) and reduce the stock holding of both the producer and retailer (so increasing turnover), the time allowed for producing and delivering food products, in particular, dairy products, has been greatly reduced. Increased consumer mobility has additionally led to greater fluctuations in demand for particular products. When taken together, these factors mean that dairy producers often receive orders for goods only hours before they are required on the shelf (Chester, personal communication).

3.6.6.3 Production schedules

The combined demands of more products and shorter deliveries have placed great pressures on production managers. They are required to make more decisions (since more products mean more ingredients and more routes) and make them rapidly. In effect, this means that a large amount of batch data must be interpreted in a short time.

Consequently, graphical representations of processes are often used to aid production planning. In particular, Gantt charts – production schedule diagrams based on the project management tool – are used to display details of product batches as they are conveyed through the process (see Fig. 3.71). Since every batch may be displayed on a single chart, production data, such as equipment utilisation and delivery times, can be rapidly appraised and used to determine future action. Since production schedules display the flow of ingredients through the plant and give details about what time individual processing units are utilised, they embody the essence of the manufacturing process.

3.6.6.4 Batch planning

Since batch schedules encompass a huge range of process data, they can be extremely time consuming to generate manually. This problem means that it is difficult for a production schedule to show current process information, so that it is often not possible to use them to plan manufacturing. According to Chester (personal communication), preparation of schedules requires detailed knowledge of:

- the throughputs of individual process units
- the recipes required to make different products
- the quantities of products to be manufactured.

Where production requirements are relatively simple and vary little, schedules can be produced sufficiently rapidly using pencil and paper. This approach is often found where plants produce only one or two products and where production takes place in a few predictable stages. However, where a large number of products are supported and where reduced delivery times require rapid planning, the preparation of production schedules may be automated by use of spreadsheet packages or, more appropriately, batch scheduling software.

3.6.6.5 Batch scheduling software

This software consists typically of a database coupled to a set of scheduling algorithms (Chester, personal communication). The database contains an imprint of the plant equipment and routeing, as well as details of the product types and recipes.

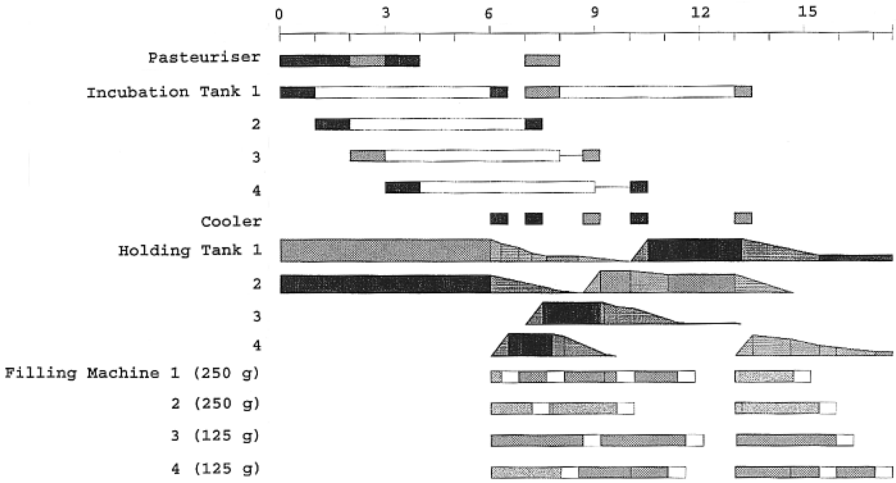

Fig. 3.71 A Gantt chart illustrates details of yoghurt batches as conveyed through the process

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The scheduling algorithms encapsulate the logic rules by which the schedule is constructed. Typically these include physical restrictions, such as "different products must be processed separately", and scheduling rules, which embody best practice for managing the process, for example "fill into the first tank which becomes available". To generate a batch schedule to meet particular production requirements, details of production orders and delivery requirements must be input into the scheduling package. This information is combined with recipe data, equipment throughput and plant connectivity to generate information on the number and size of the various material batches required to meet each product order. The scheduling rules are then applied to generate a production schedule that provides details of the timings of individual batches.

Scheduling may be done semi-automatically, with the user being prompted to confirm the size and equipment utilised by each batch, or fully automatically with user involvement being required only where the scheduling rules fail to determine a single course of action. Once generated, production schedules can be quickly manipulated to meet the varying demands placed on the manufacturing facility. Factors which have an impact on planning production include:

- achievement of customer orders
- requirement to clean equipment
- need to match operator shift patterns
- need to minimise equipment start-ups and shut-downs (thereby causing limited wastage of product and time).

3.6.7 Area/department 6

In this section the cleaning-in-place (CIP) station is located, and for further details refer to Chapter 4.

Up until now, interest has centred on the ability of the control system to monitor and control the operation of the process, but sections like filling and packaging bring about an interface with management, because if someone forgets to buy the necessary cartons, then no yoghurt can be packaged anyway. Consequently, it is vital that control systems can be expanded to collate information that will allow the management to gain access to information which is necessary to monitor the interaction of outside supplier/buyers with the company and to control the financial performance of the process plant.

3.6.8 Management information system

The large volumes of data generated by the various automation systems controlling a manufacturing process may be passed to a management information system (MIS). The MIS harnesses the incoming data to provide meaningful high level information, thus allowing rapid evaluation of the state of the process. This enables factory management to respond to changing conditions thereby improving manufacturing effectiveness (Chester, personal communication; Bird, personal communication). Typically, the MIS provides a means of integrating data from the following areas:

- Raw ingredients reception (e.g. weigh bridges for raw milk tanks)
- Process control systems
- Stock control and dispatch systems
- Packaging machines and palletisers
- Boilerhouse and other service providers.

On receipt, the MIS collates and stores data within a structured database, which may then be interrogated to provide critical information about the process. Data are displayed typically in a tabular or graphical format which elicits rapid intake. By undertaking the extraction and presentation of data, the MIS performs much of the interpretation stage which translates data into information. Thus, management information systems can provide data on inventory levels, product batching, cleaning usage and integrity, services loadings and maintenance requirements.

Management level information can be of interest not only to the processor, but also to its customers. The MIS may, therefore, provide benefits in terms of attracting large customers such as supermarket chains. For example, archiving of CIP data (e.g. temperatures, flow rates, clean duration) is used to police the rigorous hygiene standards demanded by both the producer and its major clients. By rapidly and automatically interpreting process data, the MIS equips management with the information required to take action to improve the process. Personnel are thereby empowered to manage their process more effectively; the MIS provides the conduit through which data flow from the sensor to the boardroom.

3.6.9 System architecture

The ability of the automation system to monitor and control the process and to collate and display management information requires very careful design since the demands of the two functions may be different. The balance between control and management must, according to Bird (personal communication), be decided very early in the process design, and the requirements of both the process plant

operator and the management must be balanced against both the complexity and the cost of the system. Simple plants need simple systems, but there are a few golden rules which apply to the design of a totally automated system:

- It must effectively allow the operator to control the process.
- It must effectively allow the plant manager to manage the process.
- Don't spend a pound to save a penny! (don't over-automate).
- The system must reflect the complexity of the process.

The design concept is the first stage in defining the system architecture and the wishes of all parties must be considered and weighed. Systems available in the marketplace are numerous and specialist assistance may be required in the initial process design. Most of the process plant suppliers and contractors have access to specialists who can advise on a suitable automation system once the process has been defined. The process is paramount – the automation system is there to support the process. Many good installations have been spoilt because the process has been compromised to take advantage of a cheap automation system.

The block flow chart shown in Fig. 3.72 illustrates a total automation concept based on a decentralised process control system with integral MIS. Decentralised operator interface panels allow the operator to have local control of the process, whilst an MIS system monitors and displays the relevant management information which can be displayed anywhere on the site using repeater panels.

3.6.10 System security

An MIS is generally regarded as a common database with selected access according to personal status or function. The more access that there is, the greater the danger of corrupting the system, so access must be on a strict need-to-know basis. The system will need to be protected by a password system which should be changed at frequent intervals. The passwords can be personal, or based on a personal/function basis and, in this way, access frequency can be logged against individuals.

For example, the process operator will require access to the operator interface unit to control the plant, and he/she will need both the relevant area password and a personal password. On no account can he/she be allowed to gain access to the process software. The next level of access may be the production management, who can access operator interface unit and also certain MIS elements. The extent to which specified individuals have access to the software will need to be defined. The site accountant should not normally require access to the operator interface unit, but will require access to the MIS for ingredient usage, recipe frequency, type of packaging and services utilisation. The engineering department will require access to the planned maintenance files and the services utilisation information, but, possibly, little more. The site manager may require access to all the above information, but will have restricted access to the software, whilst the system manager, who manages and maintains the whole system, will require access to every facet of the system including the software. Changes to software can only be made with his collaboration, and then only when the changes have been fully agreed and documented.

It is important also to remember that automation systems are site specific so that, while these general guidelines should give an indication of the advantages of automation, the introduction of a system needs specialist advice at every stage.

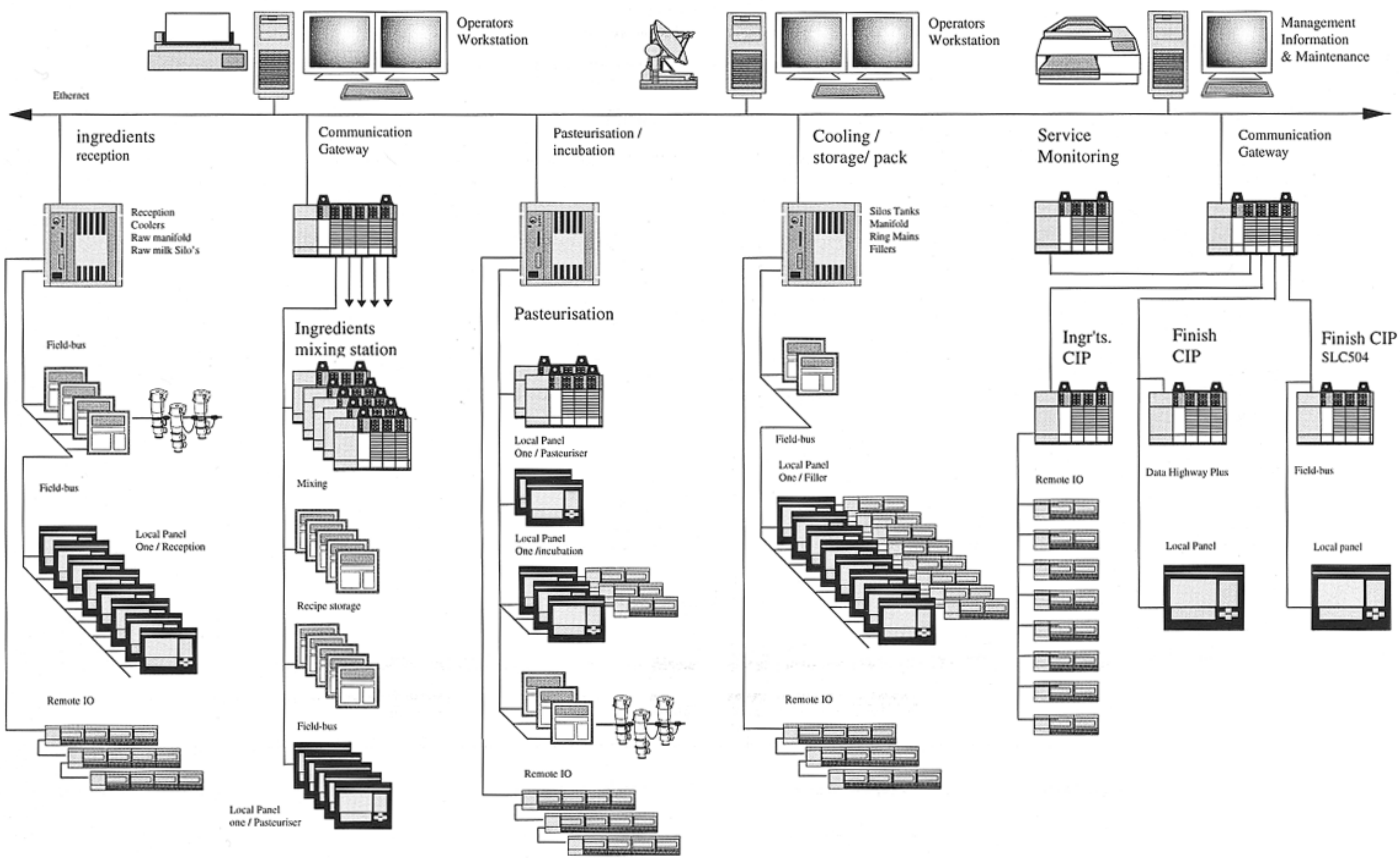

Fig. 3.72 Illustration of an automated system in a yoghurt process plant
Reproduced with courtesy of Tetra Pak (U.K.), London, U.K.

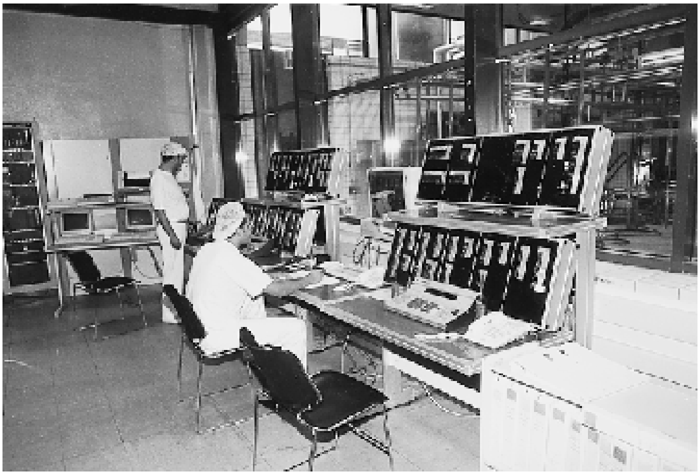

Fig. 3.73 Process control in a modern factory for the production of yoghurt and strained yoghurt

Reproduced by courtesy of Delta Dairy S.A., Athens, Greece.

Figure 3.73, for example, illustrates automation and process control for the production of yoghurt and strained yoghurt in a modern factory in Greece (see also Mortensen, 1995).

3.7 Building design, maintenance and services

3.7.1 General background and introduction

As mentioned elsewhere, the International Dairy Federation has published many documents on different aspects of dairy hygiene which include the manufacture of dairy products, processing equipment, cleaning and disinfection, storage and distribution. The latest document in this area is a manual that provides guidelines for *Hygienic Design and Maintenance of Dairy Buildings and Services* (IDF, 1997), and which includes recommendations for the plant designer of a factory that has hygienic barriers between raw materials and manufactured products. Similar manuals are also published by Campden & Chorleywood Food Research Association providing guidelines on the construction of ceilings, walls, floors and services for food production areas (Timperley, 1993, 1994) (see also Brolchain, 1993; Jolly, 1993). This approach ensures, therefore, that if a total quality management system (e.g. ISO 9000 and 9001) or hazard analysis critical control point (HACCP) system is being implemented, certification and inspection procedures for the premises are easily accommodated (see also Sowry, 1988; EU, 1992; Shapton and Shapton, 1994).

3.7.2 Location of a dairy plant

The different factors involved in locating a factory site are summarised in Table 3.7. Nevertheless, according to Timperley (1993, 1994) and IDF (1997), the layout of a dairy production unit is referred to as an operational layout which comprises dif-

Table 3.7 Summary of factors involved in selecting a location for building a new dairy plant

Main items	Sub-items
Positioning the dairy factory in the landscape	Topography Landscape Soil quality Foundation of the building
Climatic conditions	Sunshine Wind Precipitation in the form of rain or snow due to surrounding hills, vegetation and water areas Vegetation Floods Air humidity
Surrounding community	Adjacent industries Crop fields Water supply Power supply Utilisation of site area may be regulated by local authority
Society and environmental issues	Environmental legislation Public development plans Waste water disposal Noise, smoke and dust Availability of manpower
Milk supply	Delivered directly from farms and/or milk collection centre Minimise transportation time to maintain good microbiological quality of the raw milk
Preparation for extension	U-flow of production line provides: (a) space saving, and (b) extension possibilities in three directions, whilst a disadvantage makes it difficult for extension areas located innermost Straight line of production has the following advantages: (a) delivery and discharge are clearly separated, (b) easy to divide into zones (see text) to provide minimum hygiene risks, and (c) extension of most functions is only possible in two directions; the only disadvantage is that more floor area is required

Adapted from IDF (1997).

ferent departments or units. For example, in a yoghurt factory the layout consists of: (a) milk and ingredients reception, (b) milk preparation, (c) yoghurt production (including starter culture preparation/handling), (d) product packaging, (e) materials and stores, (f) cold stores, and (g) quality control laboratories. This type of layout ensures that the following aspects can be taken into consideration:

- Different but related products can be manufactured on the same site
- Equipment is expensive and stationary
- Processing times vary according to the operation
- Volumes of product sales vary.

Taking these aspects into account, it is recommended that the layout team consist of a manager, a technologist, a microbiologist, an architect and a plant operations expert and/or engineer. Furthermore, in any dairy layout where milk reception and processing take place within one enclosure or building, it is advisable that the reception and processing areas are separated. In general, the systematic approach to the design of any dairy building constitutes the "10 steps" procedure as detailed by IDF (1997).

3.7.3 Layout of a dairy plant

If a linear flow scheme has been chosen for the manufacture of yoghurt, a key aspect in hygiene design is the division of the factory into risk zones which are identified as follows:

- *Green zones* – These are areas where there is no risk of contaminating manufactured products, or areas where contamination is of minor importance. Some examples of these areas include raw milk reception, cleaning facilities for returnable containers, toilets, CIP equipment and power generators; however, these areas should be isolated from each other and in particular CIP of raw milk equipment from the rest of processing plants, toilets from raw milk reception and wet areas from dry areas.
- *Yellow zones* – These zones are regarded as areas where microbiological preventative measures are carried out. In these areas the risk of exposing the product to a contaminated environment is limited, but they are located or border a high risk red zone. Examples of yellow zones in a yoghurt factory are the store for packaging materials, laboratories, and milk processing area(s); wet and dry areas should be also separated in this zone.
- *Red zone* – In this area the strictest hygiene is required to minimise the risk of contaminating the product from the environment (e.g. air, machinery and equipment, pipes, rooms, drains and/or personnel). These areas in a yoghurt factory are identified as the bulk starter production area, yoghurt incubation tanks, processed fruit/flavours handling and yoghurt filling or packaging.

In the yellow and red zones, the following aspects should be included as criteria for verification by HACCP:

- buildings
- flow of product(s)
- personnel.

3.7.4 Design and construction of dairy buildings

Based on past experience within the dairy industry, the materials used for construction have met all criteria of durability and cleanability; however, during the construction of the wall boarding into a wall system, the hygienic conditions have been difficult to achieve at such interfaces (Timperley, 1993, 1994; IDF, 1997). However, the hygiene risk is not from the actual building structure(s), but from contamination from outside sources entering the building by various mechanisms.

In principle, the dairy building should provide a safe environment. It should:

- Protect the processing environment from extraneous matter and contamination by micro-organisms
- Provide a safe and pleasant environment and protect workers from the external environment
- Be cost effective with minimum maintenance

To achieve these aims, the building must be large enough to allow ready access between the building fabric and the equipment and sufficient space between individual items of equipment. The design of the building should provide that first, the positioning of the equipment and location of services should be away from walls in order to allow easy access for maintenance of the building, and second, the servicing, CIP and maintenance of the processing equipment should not have any detrimental effect on the fabric of the building.

Recommendations for dairy buildings have been given in detail by IDF (1997), including diagrammatic illustrations showing adequate or preferred designs in contrast to structures to be avoided. A summary of some of these recommendations might include the following.

3.7.4.1 Number of storeys

If possible, the processing area should be designed on one level, since stairs in a multilevel building are difficult to clean and permit liquids to transfer from one area to another; in a multistorey dairy, retain the main processing operations on one level.

3.7.4.2 Roofs

The roof should be fully sealed against water, rodents and birds, and some examples are: (a) if flashing is used to provide a seal, it should not form cavities, (b) the ridge points or changes in direction should be flashed, (c) the roof should be self draining towards the gutters to prevent the occurrence of ponding, (d) the roof should be sealed to the walls to prevent the backflow of water into the building, (e) exhaust fans or refrigeration plant should be mounted well clear of the roof surface to allow for run-off of liquids and space for cleaning under the equipment, and (f) cracks should be sealed and, if coating or sealant materials are used, they should be resistant to chemicals (e.g. acids or CIP vapours) and ultraviolet rays. In addition, a roof pitch $>10°$ eliminates the possibility of liquid ingress through the joints of tiles or other covering.

3.7.4.3 Gutters

Locate the gutters beyond the wall claddings and extend the roof part way down the wall before termination in the gutter in order to minimise the ingress of contaminants as a result of changing wind pressures on the walls and roof. Avoid using internal gutters because contaminants may enter the building due to blockages.

3.7.4.4 Ceilings

Ceilings should provide a barrier against dust and moisture. Some recommendations for construction are: (a) joints (i.e. on the upper and lower surfaces of the ceiling lining) should be adequately sealed, (b) ensure minimum 10° slope and proper insulation to reduce condensation, (c) provide purpose-made flashing to reduce the incidence of cracks due to thermal expansion, (d) the underside of the ceiling should be smooth, and (e) the cavity between roof and ceiling should be

accessible from outside the processing area, otherwise the access from inside should be designed with an airlock system.

3.7.4.5 Walls

Both internal and external walls should be designed and constructed to prevent the ingress of contamination, to protect against vermin, to be insulated and to ensure an absence of cracks. If sheet wall-cladding materials are used, they should be sealed at all joints and laps. It is generally recommended that (a) exposed structural membrane should be flashed and sloped to provide free draining and prevent roosting, (b) the voids in the cores of concrete blocks should be filled, otherwise cracks in the mortar joint could be a source of contamination, (c) inner surfaces should be coated with a flexible membrane coating which can be easily cleaned, and (d) mortar joints should have a 12 mm radius for easy cleaning rather than being straight.

Surface finishes of internal walls should be of materials that prevent blistering and mould growth, are resistant to milk, acids and CIP chemicals and are easily cleaned.

3.7.4.6 Access

Windows and doors (i.e. internal and external), airlocks and removable panels should be properly constructed. Some illustrations of preferred structures have been provided by IDF (1997).

3.7.4.7 Floors

Floors should be constructed to withstand heavy loads and vibration from equipment, be properly sealed and provide adequate drainage. Floor finishing materials are critical and should be easily cleaned, withstand CIP solutions including acids and be non-slippery. Epoxy resins, for example, are widely used. For further details the reader should consult Cattell (1988), Jackson (1997) and Weatherburn (1997).

3.7.4.8 Services

These include electrical wiring, ventilation ducting, drains, lighting, pressure-relief ducting, decks and platforms, stairs and piping. Specifications for such installations have been reported by IDF (1997).

3.8 Conclusion

It is evident that a multitude of factors can influence the rheological properties of yoghurt (see Chapter 2) including the mechanical handling of the coagulum (i.e. factors discussed in this chapter). Shear stress can reduce the viscosity/consistency of yoghurt, but the phenomena associated with improved firmness of the product after 24 hours storage at $<5°C$ are still not well established (see IDF, 1998). Hence, it is possible to suggest that future developments in yoghurt science and technology may include:

- Greater understanding of the physical behaviour of the coagulum after being subjected to shear stress and cooling.

- Improved milk solids formulations of the milk base (e.g. combination of SMP and WPC) and possible homogenising of the milk after heat treatment rather than before at 60–70°C.
- Provision of wider microbial blends of the starter culture to meet the requirements of the consumer and enhance the functional characteristics of yoghurt and its related products.
- Greater reliance on automation especially in large centralised factories where yoghurt is produced and improved on-line testing and monitoring of the product(s) during manufacture.
- Resurrection of the NIZO process for yoghurt production using the continuous method.

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